TECHNICAL REPORT 20

New Mexico State Engineer
Santa Fe, N. Mex.

GEOLOGY AND GROUND-WATER RESOURCES OF THE GRANTS-BLUEWATER AREA, VALENCIA COUNTY, NEW MEXICO

By

Ellis D. Gordon

Prepared in cooperation with
the United States Geological Survey

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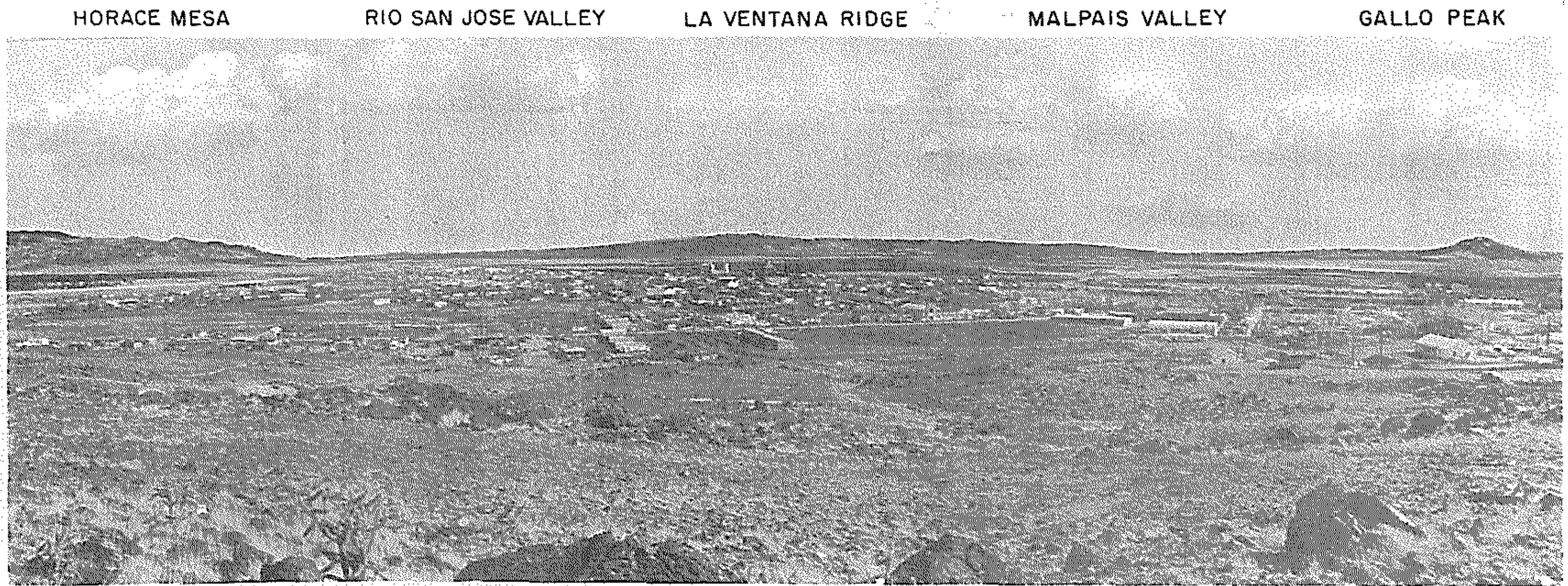

Panoramic view of the Grants area from south slope of Black Mesa, just north of Grants, Valencia County, N. Mex. The boulders in the foreground are rubble from the basalt which caps Black Mesa.

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with
a section on
AQUIFER CHARACTERISTICS

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and
a section on
CHEMICAL QUALITY OF THE GROUND WATER

By
J. L. Kunkler
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With Sections on Aquifer Characteristics

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and

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ABSTRACT

Ground water has been developed extensively for irrigation and industrial use in the Grants-Bluewater area of north-central Valencia County, N. Mex. About two-thirds of the nation's known uranium reserves are in or near this area. The development of ground water has created many problems; this report appraises the problems and their causes.

The principal aquifer in the area is formed by the Glorieta sandstone and the overlying San Andres limestone, which crop out on the flanks of the Zuni Mountains and underlie the eastern two-thirds of the area. Interbedded alluvium and basalt of Quaternary age form an aquifer of secondary importance.

The Glorieta sandstone is less permeable than the San Andres, and few wells tap it exclusively. The Glorieta transmits water to the overlying San Andres limestone, however, as pumping decreases the hydraulic pressure in the San Andres. Well-connected cavernous zones and solution channels have developed in the San Andres, and the transmissibility of the limestone is great in most places.

The alluvium and basalt yield adequate quantities of water for stock and domestic use at most places and for irrigation and municipal use locally.

The first irrigation well was drilled in 1944, and the number had increased to 23 in 1951. The use of ground water for irrigation reached a peak of 12,600 acre-feet in 1954 and has since decreased. Several of the irrigation wells have been converted for industrial and municipal supply, and ground water for these uses increased from 250 acre-feet in 1951 to 6,000 acre-feet in 1957. The total withdrawal stabilized at about 13,000 acre-feet per year from 1950 to 1957.

Withdrawal of ground water has caused water levels to decline 40 to 45 feet north of the village of Bluewater and 18 to 20 feet from Bluewater southeast to near Grants.

The largest yields are obtained from wells penetrating both of the major aquifers in the southwestern part of the Grants-Bluewater Valley between Bluewater and Milan. The yields of wells in that area range approximately from 500 to 2,200 gpm (gallons per minute); the specific capacities of the wells that were measured averaged 200 gpm per foot of drawdown. The specific capacity of only one well that taps the alluvium and basalt was determined; it was 31 gpm per foot of drawdown.

The chemical quality of the water in both aquifers varies widely in short distances. The quality of water yielded by a few wells that tap the San Andres limestone has changed in the last decade; some water has improved in quality and some has deteriorated, according to the proximity of the recharge area. The agricultural utility of water from both aquifers generally is satisfactory, although the salinity hazard of water in some areas is high. Water used for the municipal supply of Grants is too hard and too saline to be desirable, and the sulfate concentration is sufficiently high to impart an objectionable taste. The water of best chemical quality is obtained from both aquifers between Bluewater and Milan, where the largest average yields also are obtained.

INTRODUCTION

Surface-water irrigation of crops in the Grants-Bluewater area, in north-central Valencia County, N. Mex. (fig. 1), began about 1880. Water for irrigation was obtained by the early settlers by diverting a part of the flow of Bluewater Creek. Bluewater Dam was constructed in 1927 for the purpose of developing a more dependable supply of surface water. Prolonged drought during the late 1930's and 1940's greatly reduced the amount of surface water available and led to the drilling of test wells in a search for supplementary supplies of ground water. Surface water was not available for irrigation from 1952 to 1957. The first successful irrigation well was completed in 1944, and many others were completed in succeeding years. Industrial development, stemming in large part from the fact that two-thirds of the nation's known reserves of uranium ore lie within or near the Grants-Bluewater area, became significant about 1952. By 1956 the ground-water basin was in danger of being overdeveloped.

Purpose and Scope of Investigation

The Grants-Bluewater area was studied in order to evaluate the availability and quality of ground water and the probable effect of pumping upon water levels. This report presents the results of an investigation of the ground-water resources and the geology of the area by the U. S. Geological Survey in cooperation with the New Mexico State Engineer. This is a part of a continuing program of investigation of the water resources of the State.

Fieldwork consisted of establishing and maintaining a water-level-recording gage on an observation well; collecting data on domestic, stock,

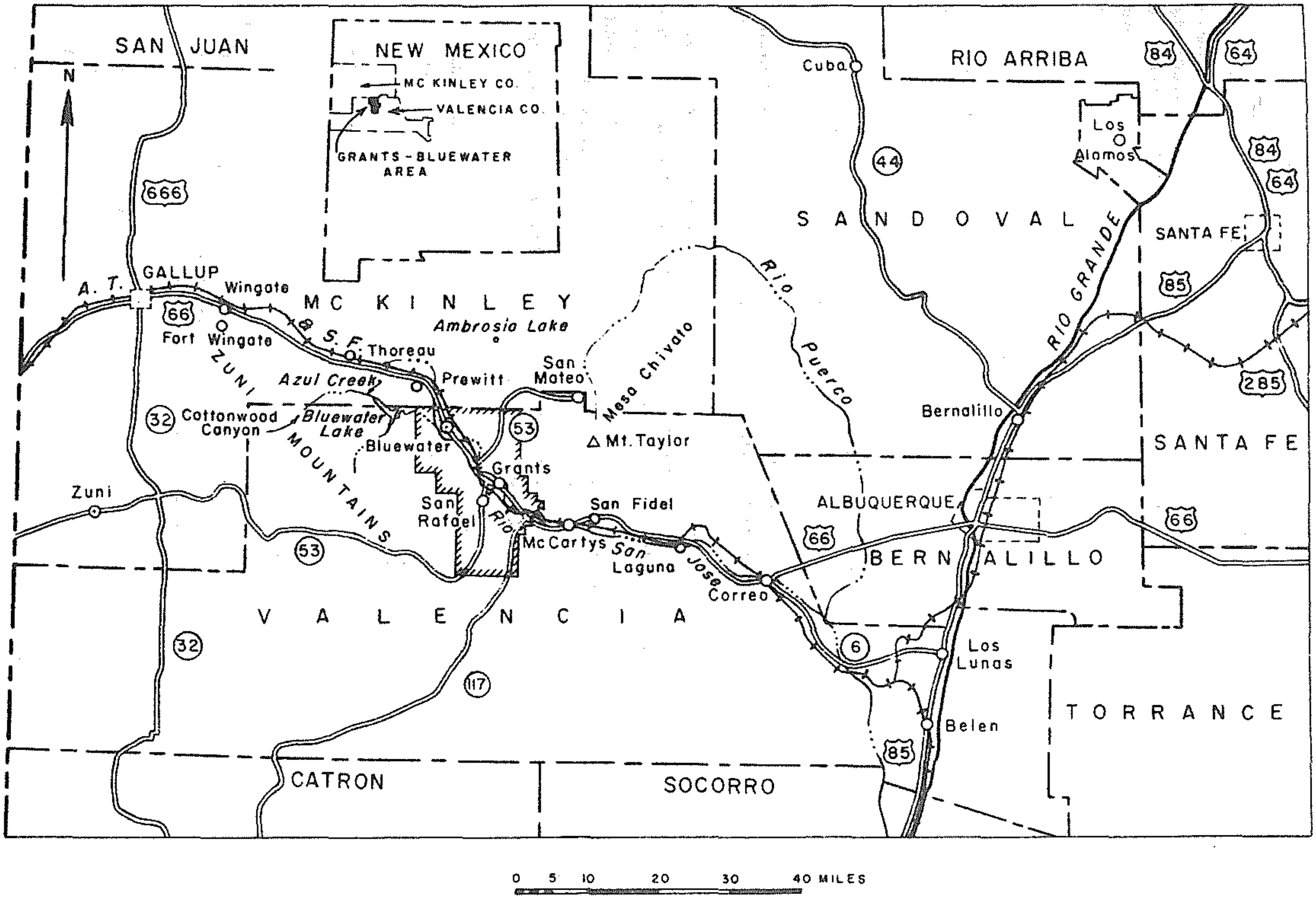


FIGURE 1. -- Map of a part of northwestern New Mexico, showing location and general features of the Grants-Bluewater area, Valencia and McKinley Counties, N. Mex.

municipal, industrial, and irrigation wells; geologic mapping; compiling acreages of irrigated lands; and collecting other related information. Aquifers were tested in a few places by controlled pumping of wells. Data from the files of the Bluewater-Toltec Irrigation District and the U. S. Department of Agriculture, Soil Conservation Service, were studied. Much information was obtained from well drillers and residents of the area.

Previous Investigations

The geology of parts of the area has been described in several earlier reports. A list of those reports and other references appears in "Selected References" at the end of this report.

The general features of the region were described by C. E. Dutton (1885) in his report on Mount Taylor and the Zuni Plateau. In his bulletin on red beds and associated formations in New Mexico, Darton (1928a) included a section on the Zuni Mountains and the Zuni-Atarque uplifts, wherein he outlined the stratigraphy of the area, described the structural relations of the Zuni Mountains and the Gallup-Zuni basin, and presented the logs of a few wells in the region.

Waring and Andrews (1935) of the U. S. Geological Survey made a reconnaissance of the ground-water resources of northwestern New Mexico in cooperation with the Public Works Administration, and their report included some data on the Grants-Bluewater area. The occurrence of shallow ground water in stream gravel and deeper water in sandstone and limestone of Permian age was noted but was not investigated further. The depth to water and the temperature and quality of water in several domestic wells at Grants and Bluewater were described briefly.

The geology and fuel resources of the sedimentary rocks in the uplands of the eastern part of the Grants-Bluewater area, in the vicinity of Mount Taylor, were described by C. B. Hunt (1936). A generalized structure-contour map of the New Mexico portion of the San Juan basin included in that report illustrates the structure of the Zuni Mountains and the Grants-Bluewater area and also indicates the location of major faults.

The igneous geology and structure of the Mount Taylor volcanic field were described by Hunt (1938) in considerable detail. The landforms and drainage of the area near Grants are treated in his report, and the late Tertiary and Quaternary history of the region is summarized.

A reconnaissance of ground water in the San Jose-Bluewater Valley, in the vicinity of Grants, was made by A. M. Morgan (1938) of the Geological Survey in cooperation with the Bureau of Indian Affairs, United Pueblos Agency. Morgan briefly described the geology and hydrology of the area. He considered the valley fill to be the principal aquifer in the valley. The gradient of the water table and movement of the water in the valley fill were treated in the report. The locations of springs in the vicinities of San Rafael, Grants, and Horace Springs were given, and their relation to faulting in the area was treated.

A few years later, C. R. Murray of the Geological Survey made a reconnaissance, in cooperation with the New Mexico State Engineer, of ground water in the Bluewater area (Murray, 1945). He concluded that three aquifers -- the basalt lava ("malpais"), the alluvium underlying the basalt, and the limestone and sandstone strata of Permian age -- might yield ground water for irrigation. Murray suggested additional study of the hydrology and geology of the area to determine the source and movement of ground water and the potential yields of aquifers.

Personnel and Acknowledgments

A program of well observation was established in the area by C. R. Murray and C. S. Conover in February 1946. The program, which included the measurement of water levels in observation wells, the installation of a recording gage in November 1946, and the collection of well data and other information, has been continued by various personnel of the Geological Survey in cooperation with the New Mexico State Engineer and has provided many of the basic data used in compiling this report. Among those who participated at various times in that phase of the investigation were U. N. Benge, F. E. Busch, W. L. Champion, G. R. Chenot, R. J. Council, A. N. Nicholson, H. O. Reeder, R. E. Smith, and J. R. Willett. J. T. Hollander worked, with some interruptions, on the investigation from August 1953 to September 1955. Fieldwork was done at irregular intervals from August 1954 to November 1957.

Thanks are expressed to the many residents of the area who provided information regarding their wells and to the well drillers who provided well logs and other related data. F. W. Freas, G. P. Roundy, and A. R. Card furnished much of the information regarding wells in the area. G. O. Bachman, C. T. Smith, R. E. Thaden, and E. S. Santos furnished manuscript geologic maps for parts of the area. S. W. West mapped much of the geology in the southeastern part of the Zuni Mountains and assisted in compiling and checking the geologic map. F. E. Busch assisted in preparation of the tables of well records and chemical analyses. W. D. Purtymun assembled the data for the section on climate and assisted in compilation of data for the geologic map.

The investigation was made under the general administration of A. N. Sayre and P. E. LaMoreaux, successive chiefs, Ground Water Branch, U. S. Geological Survey, and under the direct supervision of C. S. Conover and W. E. Hale, successive district engineers in charge of ground-water investigations in New Mexico.

The quality-of-water studies were made under the general supervision of S. K. Love, chief, Quality of Water Branch, and under the direct supervision of J. M. Stow, district chemist in charge of quality-of-water investigations in New Mexico.

Well-Numbering System

The system of numbering wells in this report, which is used generally by the Geological Survey and the State Engineer throughout the State, is based on the common subdivision of public lands into sections. The well number, in addition to designating the well, locates its position to the nearest 10-acre tract in the land network. The well number is divided by periods into four segments. In this report, the first segment denotes the township north of the New Mexico base line; the second denotes the range west of the New Mexico principal meridian; and the third denotes the section.

The fourth segment of the number, which consists of three digits, locates the well in a particular 10-acre tract. For this purpose, the section is divided into four quarters, numbered 1, 2, 3, and 4, in the normal reading order, which designate the northwest, northeast, southwest, and southeast quarters, respectively. The first digit of the fourth segment indicates the quarter section, which usually is a tract of 160 acres. Similarly, the quarter section is divided into four 40-acre tracts numbered in the same manner, and the second digit denotes the 40-acre tract. Finally, the 40-acre tract is divided into four 10-acre tracts, and the third digit denotes the 10-acre tract. Thus, well 12.10.24.342 in Valencia County is in the NE$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 24, T. 12 N., R. 10 W. If a well cannot be located accurately to a 10-acre tract, a zero is used as the third digit, and if it cannot be located accurately to a 40-acre tract, zeros are used for both the second and third digits. If the well cannot be located more closely than the section, the fourth segment of the well number is omitted. Letters a, b, c, etc., are added to the last segment to designate the second, third, fourth, and succeeding wells in the same 10-acre tract. The designation of a well location should not be considered to be the absolute location, as the section lines and the well locations are not always accurately surveyed. Wells listed in this report largely were located by automobile odometer and by inspection of aerial photographs and are believed to be accurate within 0.1 mile.

The system of numbering sections within a township and of numbering the tracts within a section is shown in figure 2.

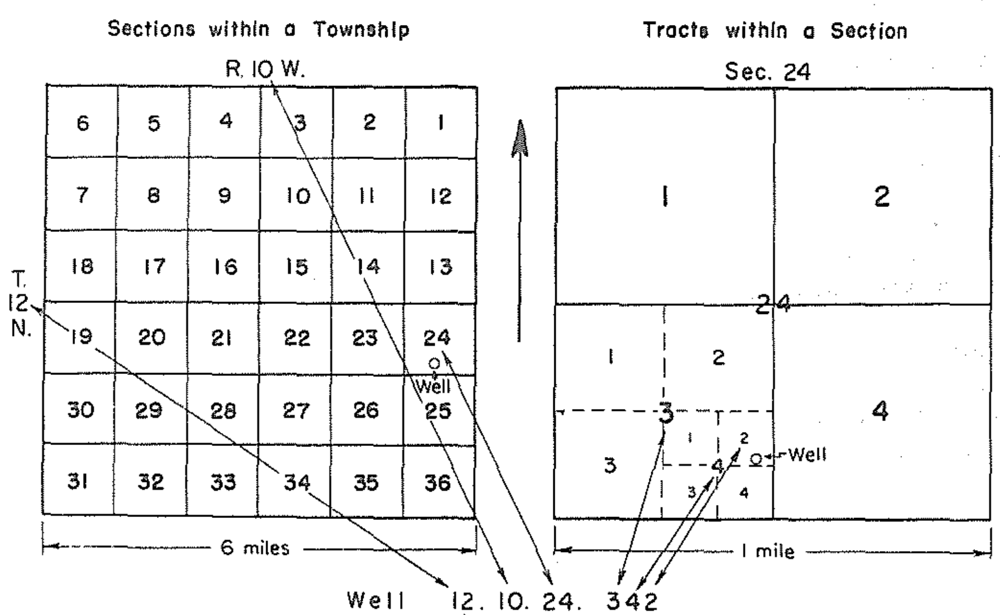


FIGURE 2. -- System of numbering wells in New Mexico.

GEOGRAPHY

Location and General Features

The principal part of the Grants-Bluewater area, as described in this report, lies 80 miles west of Albuquerque in north-central Valencia County, and a small part lies in southeastern McKinley County (fig. 1). The area includes about 650 square miles.

The principal centers of population in the area are the town of Grants and the villages of Bluewater, San Rafael, and Milan. The population of Grants in 1950 was 2,251. The populations of Bluewater and San Rafael were not determined in 1950; however, the population of Precinct 16 (Valencia County) was 371, and most of this number lived in Bluewater. The population of Precinct 17 (Valencia County) was 637, and most of this number lived in San Rafael. Because of the development of extensive uranium deposits in the region, the population of the Grants-Bluewater area has increased rapidly since 1950. The population of Grants in 1960 was 10,226. The village of Milan, adjacent to and west of Grants, was incorporated in 1957, and its population in 1960 was 2,645. The population of Bluewater and San Rafael in 1960 had not been reported at the time this report was printed but it was thought that their population probably had not changed materially since 1950. Several hundred people lived in company-built houses adjacent to the Anaconda uranium processing mill northeast of Bluewater and in various rural trailer courts in the vicinity.

In addition to the more permanent residents, large numbers of seasonal workers are employed in the area in truck-farming operations during the growing season. Most of these workers are from Indian reservations in northwestern New Mexico and northeastern Arizona.

The main line of the Atchison, Topeka, and Santa Fe Railway follows the valley of the Rio San Jose across the area. The line provides both freight and passenger service and is a major rail link between the eastern United States and the West Coast. U. S. Highway 66 parallels the railroad through the area.

The Grants-Bluewater area includes a broad valley and adjacent highlands on the flanks of the Zuni Mountains and the volcanic area surrounding Mount Taylor. The Zuni Mountains have a general altitude of 8,000 feet. Mount Sedgwick, the highest peak in the Zuni Mountains, rises to an altitude of 9,256 feet. East of the area, Mount Taylor, 11,389 feet in height, is surrounded by flat-topped lava-covered foothills which lie at altitudes of 8,000 to 9,000 feet. Mount Taylor rises about 3,000 feet above the surrounding mesas and about 5,000 feet above the valley of the Rio San Jose. Sedimentary rock strata dipping northeastward from the Zuni Mountains disappear beneath the alluvium in the valley at altitudes from 6,500 to 6,600 feet. The northern and eastern parts of the area are bounded by prominent escarpments of sedimentary strata facing the valley. The principal irrigated area lies in the valley between Grants and Bluewater at an altitude of 6,600 feet.

Haystack Mountain, a large flat-topped butte, is a prominent topographic feature a few miles north of Bluewater, and 5 miles east of Prewitt. Uranium in commercial quantities was first discovered in New Mexico at Haystack Mountain in 1950.

Just south of Haystack Mountain, 5 miles north-northeast of the Bluewater railway station, is a low volcanic cone known as El Tintero (the inkwell or inkstand). This basaltic lava cone marks the source of a broad basalt flow that covers much of the valley area southward and southeastward from Haystack Mountain to Toltec, a few miles northwest of Grants. Other basalt flows, which emanated from sources in the Zuni Mountains, are exposed in the valley area from just west of Grants southeastward across Malpais Valley and down the valley of the Rio San Jose to the vicinity of McCartys. A series of flat-topped mesas capped with basalt are prominent topographic features north and northeast of Grants. (See plate 2.)

The major part of the Grants-Bluewater area lies within the Rio San Jose basin. The course of the Rio San Jose generally is southeastward from the continental divide area near Thoreau to its confluence with the Rio Puerco, 30 miles southwest of Albuquerque. The Rio Puerco in turn is a tributary of the Rio Grande. The channel of the Rio San Jose generally is dry, except immediately after heavy rains. Springs issuing from the basalt and alluvium a few miles southeast of Grants maintain a small perennial flow in the Rio San Jose in the southeastern part of the Grants-Bluewater area.

Bluewater Creek, which heads in the Zuni Mountains north of Mount Sedgwick, is the principal tributary of the Rio San Jose in the Grants-Bluewater area. The creek flows northward to its junction with Azul Creek, then eastward to its junction with the Rio San Jose. Bluewater Dam was built in 1927 at the junction of Azul and Bluewater Creeks. Prior to the completion of the dam, Bluewater Creek was a perennial stream as far as the mouth of Bluewater Canyon, 5 miles northwest of Bluewater.

Prop, Pole, Limekiln, and Zuni are the principal canyons southeastward from Bluewater Canyon that open into the valley areas along the northeastern flank of the Zuni Mountains. Of these, Zuni Canyon is the largest and most deeply incised. The Zuni Canyon road, extending through the canyon southwestward from Grants, provides access to the Zuni Mountains.

The broad basalt-floored Malpais Valley is south of Grants. The basalt flows emanated from volcanoes near the southeast end of the Zuni Mountains and flowed eastward, then northward down Malpais Valley to the Rio San Jose valley. A narrow tongue of basalt of Recent age lies along the east margin of Malpais Valley and extends eastward a few miles along the Rio San Jose valley to the vicinity of McCartys.

The Zuni Mountains form one of the most prominent features of the region, an elongated asymmetrical dome trending northwestward. The uplift is 70 miles long and 30 miles wide, extending along the southwestern side of the Grants-Bluewater area.

A series of alternating cuestas and valleys have been formed by the tilted sedimentary strata. The steep faces of the cuestas are facing inward toward the center of the uplifted area; long dip slopes facing outward have been developed on the more resistant strata. Long valleys running parallel to the main trend of the uplift have been created by erosion of the less resistant formations. Much of the Grants-Bluewater area lies in such a valley that has been eroded into the less resistant strata of the Chinle formation. Dips in the sedimentary strata surrounding the dome are somewhat steeper than the surface slopes.

Climate

The Grants-Bluewater area is semiarid to arid, and the average annual temperature is about 50°F. Maximum summer temperatures exceed 100°F only rarely. Minimum winter temperatures occasionally may fall below 0°F. Moderate to strong winds are common during the spring. Sunny days are prevalent, and the humidity usually is low. The daily range in temperature is great; the days are warm and sunny, and the nights are cool. Because of considerable differences in altitude between the valleys and the mountains, temperature, precipitation, and evaporation rates vary widely in the general region. Annual precipitation at weather stations in the region is shown in figure 3.

Weather stations are maintained at Bluewater and at the airport near Grants. The average yearly precipitation at Bluewater is 10.10 inches and that at Grants is 8.31 inches. Precipitation presumably is somewhat greater in the mountains and evaporation less than in the valley. Climatological data in the general region are given in table 1.

Approximately 70 percent of the total yearly precipitation in the Grants-Bluewater area is concentrated in the period from May through September. July, August, and September usually are the wettest months. Mean monthly precipitation at Bluewater is shown in figure 4. The distribution of rainfall is advantageous for growing crops, but the amount of precipitation usually is inadequate and must be supplemented by irrigation.

Most of the precipitation during the summer is in the form of rain accompanying scattered local thunderstorms; total yearly precipitation, therefore, may vary widely from place to place in the valley. Snowfall during the winter increases considerably with altitude. Some snow usually accumulates in the higher parts of the Zuni Mountains and on Mount Taylor during the winter but melts in the early spring.

A graph showing the cumulative departure from average precipitation in the Grants-Bluewater area from 1896 to 1956 was prepared from records of several weather stations in the region (fig. 5). It illustrates the recurrence of wet and dry periods in the general vicinity. The record indicates that precipitation was deficient from 1898 to 1903 and from 1912 to 1918. Precipitation was slightly above average in the period 1919-36. The years 1931-36 and 1940-41 were prevailingly wet. The years 1942-56 generally were deficient in precipitation.

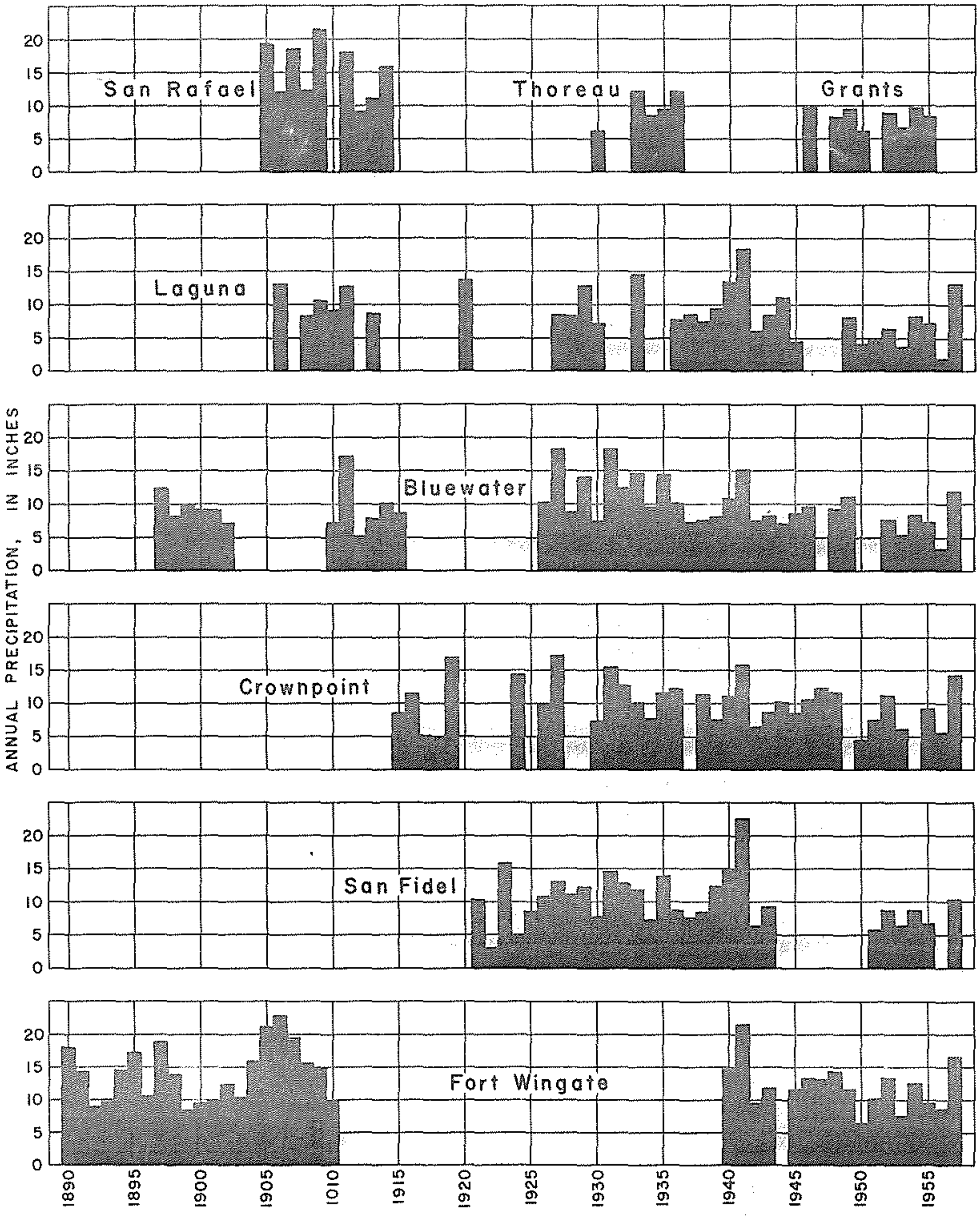


FIGURE 3. -- Annual precipitation at weather stations in the general vicinity of Grants and Bluewater, Valencia and McKinley Counties, N. Mex.

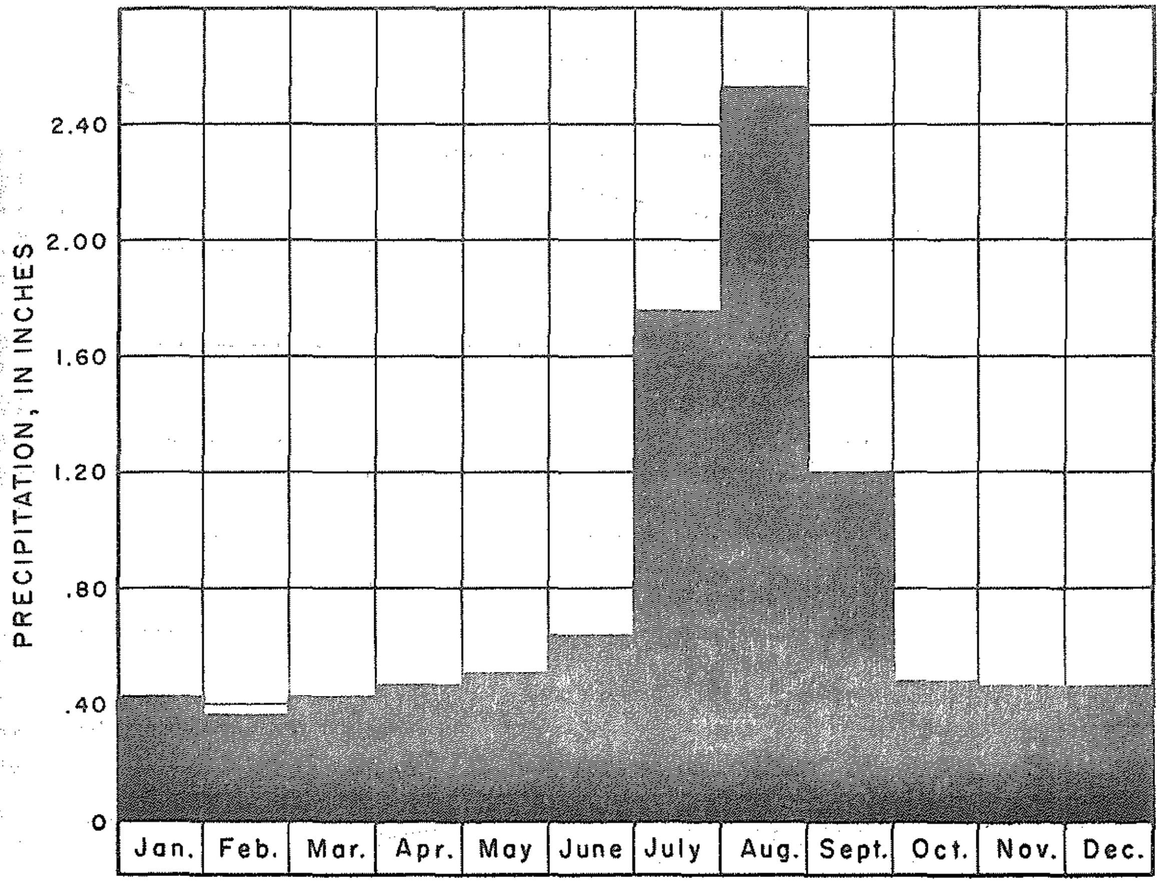


FIGURE 4. -- Mean monthly precipitation at Bluewater, Valencia County, N. Mex.

Data on the rate of evaporation in the immediate area are not available, but the records indicate an average evaporation rate of 91.4 inches per year from a special land pan measuring 6 x 36 x 36 inches at Gamerco in western McKinley County, during the period 1922 to 1928.

The length of the growing season varies somewhat within the area. The average date of the last frost (32°F) at Bluewater is May 30, and the average date of the first frost is September 23; the average length of the frost-free season in that vicinity, therefore, is 116 days. The average date of the last frost at Grants is May 21 and that of the first frost is October 12; the average length of the frost-free season in that vicinity is 144 days. The duration of the frost-free season varies widely, however, from year to year.

Agriculture

The major part of the area is utilized for the grazing of livestock. Farming is restricted largely to the valleys -- Bluewater Creek and Rio

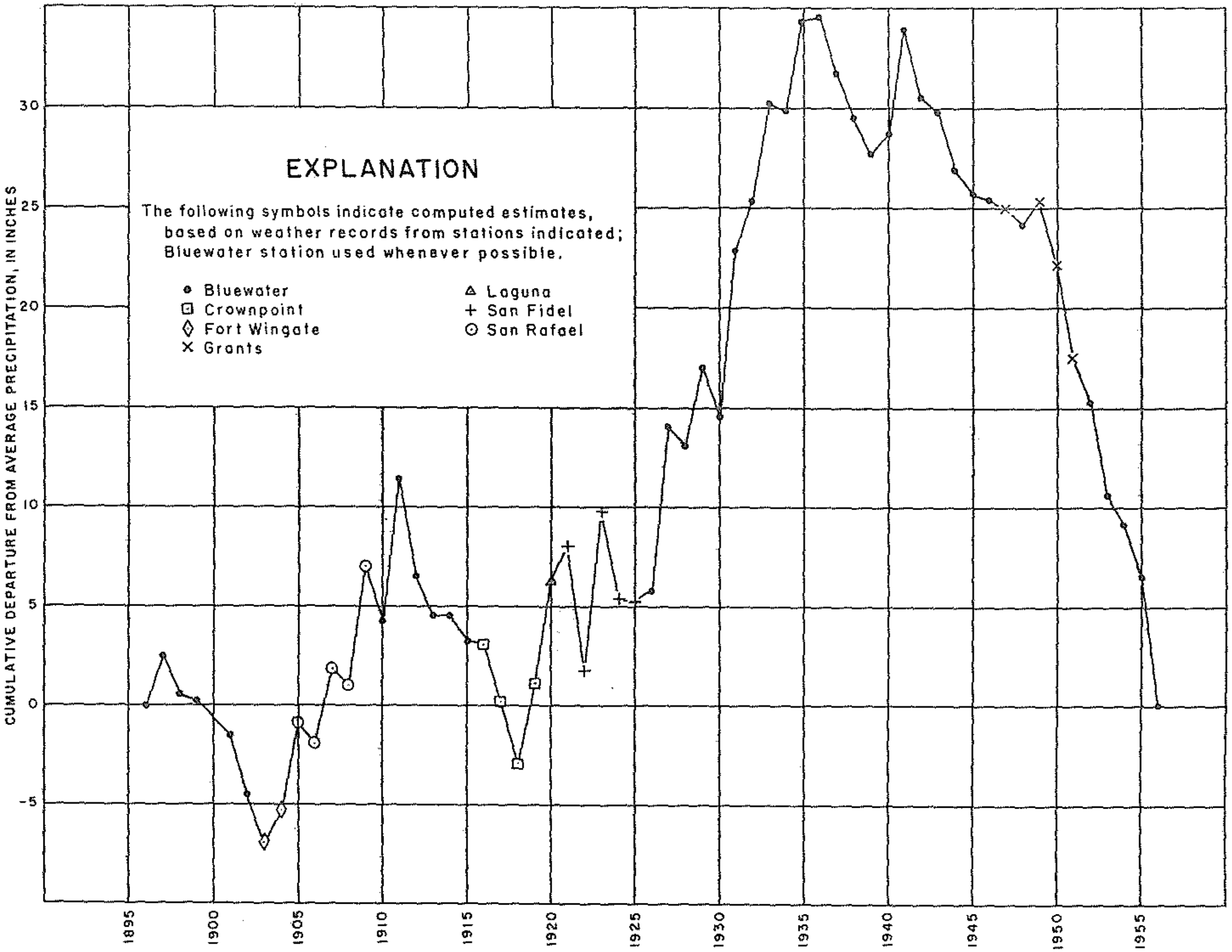


FIGURE 5. -- Cumulative departure from average precipitation in the Grants-Bluewater area, 1896-1956, based on weather records from Bluewater, Grants, San Rafael, San Fidel, Laguna, Crownpoint, and Ft. Wingate, Valencia and McKinley Counties, N. Mex.

San Jose in the vicinity of Bluewater and Grants and along the western side of Malpais Valley in the vicinity of San Rafael. Some land in the Rio San Jose valley in the eastern part of the area, near Horace Springs, is suitable for farming. Because of the low annual precipitation, supplemental supplies of water for irrigation are needed for raising crops.

Much of the farmland in the valley is used for truck farming. About 1,200 acres of land is planted to carrots each year. Other vegetables raised include peas, lettuce, cabbage, and potatoes. About 1,500 acres of land was planted to vegetables in 1957.

The principal feed crops are alfalfa, corn, grain sorghums, oats, and barley. Most of the crops raised for feed are used locally. About 1,800 acres was planted to hay and other feed in 1957.

Settlers first moved into the Grants-Bluewater area in the 1880's and began irrigation shortly thereafter. The early settlers obtained surface water for irrigation by diverting a part of the flow of Bluewater Creek into community ditches. The flow of Bluewater Creek was not controlled at that time, and the stream was perennial as far as the mouth of Bluewater Canyon, a few miles northwest of Bluewater. The creek was intermittent below the mouth of Bluewater Canyon, flowing only during spring runoff and after heavy rains on the watershed.

In order that the flow of the creek might be regulated, several companies, such as the Bluewater Land and Irrigation Co. and, later, the Bluewater Development Co., were organized. In 1894, a low earthen dam was constructed on Bluewater Creek below its confluence with Azul Creek, at the site of the present Bluewater Dam. This dam provided a reservoir for storage of 20,000 acre-feet of water, but the amount stored was insufficient for the needs of the area. The first earthen dam was washed out in 1905. A second earthen dam, between 30 and 40 feet in height, was then constructed on the same site. The second dam was washed out in September 1909. Land in the valley again was irrigated by diversion from Bluewater Creek for several years after the destruction of the second earthen dam. The amount of land irrigated during this interval varied from year to year but averaged from 2,000 to 2,500 acres per year.

The Bluewater-Toltec Irrigation District was organized in 1923 and is still operative. The Irrigation District erected the present Bluewater Dam in 1927. The structure, of reinforced concrete, is 80 feet high, and provides storage of 45,500 acre-feet of water. Bluewater Creek is used as the main canal from the dam to the upper end of the irrigated valley, 6 miles downstream from the reservoir.

Four main canals were constructed in the valley. The canals were intended originally to distribute water to 10,627 acres of irrigable land in an area extending from the mouth of Bluewater Canyon southeastward to the vicinity of Grants. Unfortunately, the irrigation system was not entirely successful. Precipitation on the watershed above the dam was not as great as had been anticipated, and the reservoir never has been full. The water level was only a few inches below the spillway crest in 1941, but it was lowered by the siphon spillway. Runoff from the watershed into the reservoir has been relatively light since 1941.

Water was available only for a part of the irrigable land during years of relatively heavy precipitation, and little or no water was available for irrigation during dry years. The original 10,627 acres of land scheduled for irrigation had been reduced to 5,488 acres by 1948. The remainder of the land was permanently excluded from the district, and all available water was reserved for the 5,488 acres.

Supplies of surface water for irrigation since 1944 have been available only in 1948, 1949, and 1952. Moreover, the amount of surface water available during these 3 years was sufficient to irrigate only 1,500 to 2,000 acres of land.

Summaries of the flow in Bluewater Creek during the period 1913-56, the acres estimated to be irrigated by surface water in the Bluewater-Toltec Irrigation District, and the amount of surface water estimated to have been applied to irrigated lands, are given in table 2.

Natural Resources and Industry

Ground water in the study area is used for irrigation, industrial, municipal, stock, and domestic purposes. Water is a renewable resource to some extent and is often taken for granted; however, its importance in the economy of the Grants-Bluewater region can hardly be overemphasized.

The main industries of the area until recent years were ranching and farming. Some income was derived from the tourist trade and from small-scale logging operations. A sawmill just south of Grants provides native lumber for the area.

Most of the land is utilized for raising livestock, except for the irrigated lands in the valley. Since about 1939, irrigated crops have been vegetables primarily, and facilities have been constructed for washing, processing, and packing carrots and other vegetables.

The Grants-Bluewater area is now undergoing a change from a predominantly agricultural to a predominantly industrial economy. The primary cause of this change was the discovery in 1950 and 1951 of large deposits of uranium nearby. Exploratory work indicated that the deposits were of considerable magnitude. Large deposits of uranium ore are now being mined north and east of Grants in Valencia County and in the Ambrosia Lake area in southeastern McKinley County. Estimates of ore reserves issued by the Atomic Energy Commission in 1957 indicate that 68 percent of the presently known uranium reserves of the United States are in northwestern New Mexico, in the region north, east, and northwest of Grants.

In 1952, the Anaconda Co. built a large uranium-processing mill in the valley just northeast of Bluewater in an area where ground water in large quantities was available. The company drilled two large-capacity wells and later purchased adjoining agricultural lands on which five additional large-capacity wells were located.

Continued exploration for uranium led to mining in the Ambrosia Lake area 20 miles north of Grants and indicated the need for additional uranium mills in the area. At the end of 1957, two additional mills were under construction 6 miles north of Grants by the Homestake Mining Co. in partnership with various mining groups, and large mills were under construction in the Ambrosia Lake area by Phillips Petroleum Corp. and by Kermac Nuclear Fuels, Inc. The Dow Chemical Corp. constructed an alkali terminal a few miles northwest of Grants for distribution of chemicals, principally caustic soda and soda ash, to uranium mills in the area. Most of the workers for both construction and mining operations live in the Grants-Bluewater area.

Perlite mined on the south side of East Grants Ridge, a few miles northeast of Grants, is processed in Grants. Production of the plant in 1957 was estimated to be about 72,000 tons. Pumice from the same general locality was mined during World War II and was processed in the mill at Grants. Fluorspar and copper have been mined from rocks of Precambrian and Permian age in the Zuni Mountains southwest and west of Grants; however, these mines have been inoperative for the past several years.

Road metal for fill and surfacing has been obtained from several beds of limestone and sandstone and from basalt flows in the area. Timber has been logged at various places in the Zuni Mountains and the Mount Taylor area.

In order to house and provide necessary facilities for its large labor force, Grants has expanded rapidly. Many new trailer courts have been developed in the vicinity and, in 1957, the village of Milan was established just west of Grants. The Anaconda Co. constructed housing for its employees in an area adjacent to the mill site. Auxiliary industrial concerns, such as mining-supply firms and concrete-products companies, have been established to serve the growing needs of the area.

GEOLOGY

The geologic formations exposed in and near the Grants-Bluewater area range in age from Precambrian to Recent; however, not all the geologic periods are represented.

The exposed rocks are sedimentary, with the exceptions of igneous and metamorphic rocks of Precambrian age and basalt flows of late Tertiary and Quaternary ages. Igneous and metamorphic rocks of Precambrian age are exposed in the central part of the Zuni Mountains along the southwestern margin of the Grants-Bluewater area. The exposed sedimentary rocks range in age from Pennsylvanian(?) to Quaternary. Basaltic lava flows of later Tertiary age cap high ridges and mesas in the area. Basaltic lava flows of Quaternary age are interbedded with alluvium in the valleys.

A generalized stratigraphic section of the geologic formations, their general physical character, and their general water-bearing characteristics are shown in table 3, and the areal geology is shown in plate 1. Although the major part of the Grants-Bluewater Valley lies in Valencia County and the hydrologic studies were restricted to that county, an adjacent part of McKinley County was included in the geologic map in order to provide a more complete geologic setting.

Summary of Geologic History

The general region of the Zuni uplift apparently was high topographically throughout much of geologic time before the Pennsylvanian period. The area then became low enough for deposition of sediments, and strata of Pennsylvanian(?) and Permian age were deposited. After deposition of the San Andres limestone, Permian in age, the region was uplifted and eroded prior to the deposition of Triassic strata. This hiatus extended through the latter part of the Permian period (post-Leonard time) to about Middle Triassic time. A karst topography was developed on the San Andres limestone in parts of the Grants-Bluewater area during that period of erosion. The San Andres limestone was removed by erosion in some parts of the Zuni uplift east of Gallup, N. Mex., and strata of Triassic age were deposited directly on the Glorieta sandstone. Drillers' logs of irrigation wells in the Grants-Bluewater area contain numerous references to sand, gravel, and silt in the San Andres limestone. These alluvial materials probably were washed into solution channels in the limestone, during the time that the San Andres was exposed to erosion. Other solution channels and cavities have remained unfilled. Drillers have reported numerous wells in which drilling tools have fallen free in open cavities in the limestone. These solution channels and cavities probably were developed initially during the post-Leonard erosional interval and were enlarged further during later periods of erosion.

After the post-Leonard erosional interval, continental sediments were deposited in Middle(?) and Late Triassic and Late Jurassic times. Both marine and continental sediments were deposited in Late Cretaceous time. The region was subjected to erosion at intervals during Early Jurassic and Early Cretaceous times and has been subjected to erosion since the end of the Cretaceous period. The Zuni Mountain area was uplifted sharply, and the sedimentary strata were folded and faulted at that time.

Extensive basalt flows of late Tertiary age were deposited on beveled Cretaceous strata in the Mount Taylor area. Subsequent erosion reduced the elevation of much of the surrounding land surface more than 700 feet, so that the lava flows now cap high mesas. Erosion during the Quaternary period extended downward 150 feet or more below the present valley level. The early valleys have been partly filled by deposits of Quaternary alluvial material and basalt flows.

Structure

The Grants-Bluewater area is on the northeastern flank of the Zuni uplift, an elongate, elliptical dome trending northwestward. Strata in the central part of the Zuni Mountains have been uplifted vertically several thousand feet. Crystalline rocks of Precambrian age and sedimentary strata of Pennsylvanian(?), Permian, Triassic, Jurassic, and Cretaceous ages have been exposed by erosion of the dome.

The sedimentary strata in the Grants-Bluewater area dip gently northward to eastward into the San Juan basin and the Acoma-Laguna embayment. The San Juan basin is a broad structural depression that extends northward for many miles in northwestern New Mexico and southwestern Colorado. The strata usually dip from 2 to 5 degrees, but local differences in dip are common. In the eastern part of the area, near the western margin of La Jara Mesa and southward through the eastern part of Malpais Valley, the strata dip steeply eastward into the McCartys syncline, a broad, shallow, northward-plunging fold that passes under the Mount Taylor area and extends northward into the southern part of the San Juan basin.

Geologic structures in the Grants-Bluewater area are related to the uplift of the Precambrian core of the Zuni Mountains. The rocks of the area are cut by numerous normal faults. Near the fault zones, considerable variation in dips of strata and changes in direction of dip have resulted from drag along the faults. Many of the faults are *en echelon*, and the relations of individual faults within the fault zones usually are complex. Displacements along the faults usually are small, from a few feet to a few tens of feet. Some of the faults, however, extend for several miles and have displacements of several hundred feet (fig. 6).

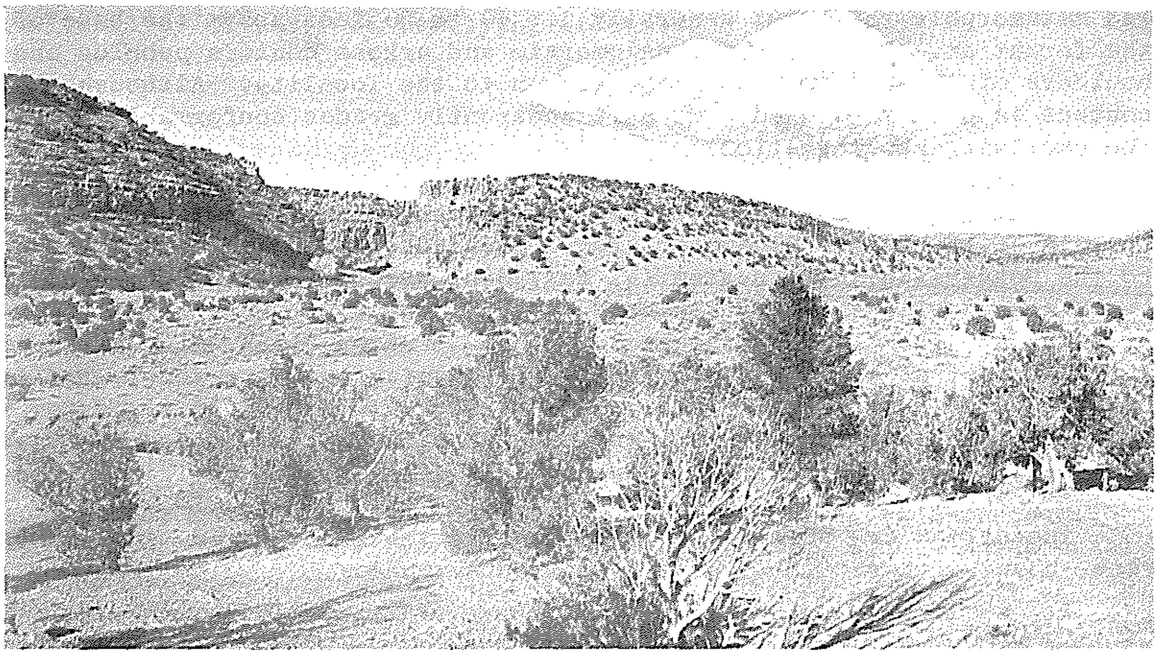


FIGURE 6. -- Fault scarp and exposed strata at mouth of Bluewater Canyon, at the upper end of the Grants-Bluewater Valley. View northwestward and northward from a point one-fourth mile southeast of the mouth of the canyon, in the SW¼ sec. 8, T. 12 N., R. 11 W., Valencia County, N. Mex.

Geologic Formations

Precambrian System

Igneous and metamorphic rocks of Precambrian age are exposed in the central core of the Zuni Mountains in the southwestern part of the Grants-Bluewater area. These rocks consist of granite, gneiss, metarhyolite, schist, and greenstone. They have been folded, faulted, and metamorphosed, and are overlain by sedimentary strata of Late Pennsylvanian(?) age.

The water-bearing properties of the Precambrian rocks were not determined, but they are too deeply buried to be considered as a source of water for most of the Grants-Bluewater area.

Pennsylvanian(?) System

Conglomerate, arkose, shale, and limestone immediately overlying the igneous and metamorphic rocks of the Zuni Mountains have been designated as Pennsylvanian(?) in age. These rocks are as much as 125 feet thick in the southeastern part of the mountains, but they wedge out to the northwest in the mountains. The section of Pennsylvanian(?) rocks thickens eastward and northeastward from the Zuni uplift. Impure arkosic lenses of limestone containing pre-Wolfcamp fossils occur within the conglomerate and arkose. Thompson (1942) stated that these lenses probably are equivalent in age to the Virgil series (of Late Pennsylvanian age). The lenses of limestone in some places immediately overlie the igneous and metamorphic rocks but generally lie 40 to 50 feet above the base of the formation. The beds of conglomerate and arkose contain pebbles and boulders of the Precambrian rocks common to the locality. Although the contact is poorly exposed, the unit apparently grades conformably into the overlying Abo formation.

Strata of Pennsylvanian(?) age are not shown on the geologic map (pl. 1) of the Grants-Bluewater area. Limestone and conglomerate assigned to the Pennsylvanian(?) system (N. Mex. Geol. Soc., 1951, p. 30) crop out in an area 2 miles west of the head of Zuni Canyon but have been included with the Abo formation on the geologic map. Foster (1957, p. 66) reported that 175 feet of strata of possible Pennsylvanian age were penetrated in the Tidewater No. 1 Mariano well, in sec. 8, T. 15 N., R. 13 W., a few miles northwest of Thoreau, N. Mex., and that the Larrazolo No. 1 Gottlieb, in sec. 21, T. 10 N., R. 9 W., penetrated 480 feet of Pennsylvanian beds.

The strata are buried deeply in most of the report area, and their water-bearing characteristics were not determined.

Permian System

Sedimentary strata of Permian age, 1,500 to 2,000 feet thick, underlie the Grants-Bluewater area. The strata are assigned, in ascending order, to the Abo, Yeso, Glorieta, and San Andres formations. The formations are well exposed in the central part of the Zuni Mountains northwest of the head of Zuni Canyon and in the walls of the numerous canyons draining the northeast flank of the uplift.

Abo Formation

The Abo formation is exposed widely in the central part of the Zuni uplift. It is composed of dark brick-red to reddish-brown arkosic or quartzose sandstone and siltstone and numerous layers of conglomerate in the lower part of the formation. Fossils are sparse. The most common fossils are impressions of reeds and other marsh-type vegetation. Bedding is predominantly slabby; crossbedding is prominent in the lower part of the formation, and evenly bedded layers are more numerous in the upper part. The Abo appears to be overlain conformably by the Yeso formation in most places, although a few inches of relief is apparent at the top of the formation in some exposures. The Abo ranges in thickness from 500 to 800 feet in the Zuni Mountains and is somewhat thinner in the area southwest of the Zuni Mountains. Logs of oil tests indicate that the Abo is 450 to 500 feet thick in this area. The Abo is 780 feet thick in a section measured by C. B. Read at the upper end of Cottonwood Canyon, 12 miles south-southwest of Thoreau, N. Mex. The measured section is presented on page 20.

Because the Abo formation is buried deeply beneath the Grants-Bluewater area, little is known of its water-bearing properties. The beds of silty sandstone and sandstone probably would yield adequate quantities of water to wells for stock and domestic use in favorable localities. The formation has not been tested, however, because of the availability of water in overlying strata.

Yeso Formation

The Yeso formation crops out in a band surrounding the central core of the Zuni uplift. The upper part of the formation in the Grants-Bluewater area is exposed in the walls of the deeper canyons incised into the strata of Permian age on the northeast flank of the uplift. The formation is well exposed in the upper part of Zuni Canyon, west of Grants. The uppermost beds of the formation are exposed at the lower end of Bluewater Canyon and southward from the canyon along the fault scarp.

The Yeso formation, which is shown as a unit on the geologic map (pl. 1), is divisible into two members in this region. The lowermost member, the Meseta Blanca sandstone, is a crossbedded, fine-grained, quartzose sandstone that weathers to massive rounded ledges. The basal part of the member in places is composed of a few feet of thinly bedded brownish-red siltstone. The sandstone usually is reddish brown and commonly is pinkish brown to orange in weathered exposures. The member ranges in thickness from 100 to 150 feet. Much greater thicknesses have been reported by some geologists in the region. The discrepancy in reported thicknesses may be due to the selection of different points for the contact between the Meseta Blanca and the underlying Abo formation. The Meseta Blanca sandstone member is 102 feet thick in a section measured by C. B. Read and A. A. Wanek in the Zuni Mountains at the upper end of Cottonwood Canyon, 12 miles south-southwest of Thoreau, N. Mex., a short distance west of the Grants-Bluewater area. The section follows.

Section of Permian rocks measured by C. B. Read and A. A. Wanek at the upper end of Cottonwood Canyon, in secs. 4, 8, 9, 16, and 17, T. 12 N., R. 14 W., Valencia County, N. Mex.

		Thickness (feet)
Upper Triassic system:		
Chinle formation:		
Shinarump member:		
Conglomerate; unit not measured.		
Unconformity.		
Permian system:		
San Andres limestone		50
Limestone, siliceous, light-brownish-gray to grayish-orange-pink, medium- to thick-bedded, evenly bedded, fossiliferous, weathers in vertical cliffs. Upper part of unit is crystalline, lower part of unit moderately silty. Apparently, an ancient karst topography was developed on surface of the limestone member. The member is locally absent owing to pre-Triassic erosion. Thickness measured	50	
Glorieta sandstone		290
Sandstone, grayish-orange-pink, fine-grained, cross-laminated, medium- to thick-bedded, well cemented with calcium carbonate, weathers in irregular to vertical cliffs	190	
Sandstone, grayish-pink, very fine- to fine-grained, thin- to medium-bedded, moderately argillaceous, cemented with calcium carbonate, abundant ferruginous pitting; weathers in irregular cliff	100	
Yeso formation		412
San Ysidro member (310 feet):		
Sandstone, pale-red to pale-reddish-orange, fine-grained, argillaceous, evenly bedded, thin- to medium-bedded, cemented with ferric oxide and calcium carbonate, weathers in regular slope. Unit poorly exposed	30	
Limestone, light-brownish-gray, evenly bedded, thin-bedded, granular, well-jointed; weathers in vertical ledges	1	
Sandstone, pale-red, fine-grained, argillaceous, thin-bedded, minor thin siltstone beds intercalated in sandstone, cemented with ferric oxide and calcium carbonate, weathers in irregular cliffs	22	
Sandstone interbedded with siltstone, pale-reddish-brown, fine-grained, argillaceous, evenly bedded, thin- to medium-bedded, cemented with ferric oxide and calcium carbonate, weathers in irregular slopes	48	

Section of Permian rocks (continued)

	Thickness (feet)
Permian system (continued)	
Yeso formation (continued)	
San Ysidro member (310 feet) (continued)	
Limestone, silty, light-brownish-gray, granular, evenly bedded, thin-bedded. Limestone contains small vugs of cryptocrystalline calcium carbonate. Weathers in vertical cliffs 9	
Siltstone interbedded with shale, yellowish-gray, very fine-grained, even to crinkly bedded, thin- to medium-bedded, cemented with calcium carbonate; thin lenses of silty limestone interbedded with shale. Weathers in irregular ledges 10	
Sandstone interbedded with siltstone, grayish-orange-pink with some light-gray banding, fine-grained, argillaceous, evenly bedded, thin-bedded, cemented with calcium carbonate. Occasional beds of sandstone are cross-laminated. Weathers in irregular slopes. Unit poorly exposed 64	
Limestone, siliceous, olive-gray to light-brownish-gray, granular, thin- to medium-bedded, well-jointed, silty partings in limestone beds, abundant vugs of crystalline calcium carbonate, weathers in irregular ledges 10	
Sandstone interbedded with siltstone, light-brown to reddish-brown, evenly bedded, thin- to medium-bedded, very fine- to fine-grained, argillaceous, cemented with calcium carbonate and ferric oxide deoxidation mottling common; unit weathers in rolling slopes. Unit poorly exposed 116	
Meseta Blanca member (102 feet):	
Sandstone, reddish-brown, very fine- to fine-grained, argillaceous, thick-bedded to massive, weakly cemented with calcium carbonate and argillaceous materials; weathers in rounded or domed cliffs 102	
Abo formation	780
Sandstone interbedded with siltstone, reddish-brown to pale-reddish-brown, evenly to irregularly bedded, thin- to medium-bedded, very fine- to fine-grained, with occasional medium-grained sandstone beds; argillaceous, cemented with calcium carbonate and ferric oxide deoxidation mottling very common; weathers in slopes. Poorly exposed 316	

Section of Permian rocks (continued)

	Thickness (feet)
Permian system (continued)	
Abo formation (continued)	
Sandstone, reddish-orange with grayish-pink mottling, fine-grained, argillaceous, evenly bedded, thin-bedded, cemented with ferric oxide and calcium carbonate; surface markings include rain pits, slime marks, and abundant ripple marks; weathers in regular slopes	71
Sandstone interbedded with siltstone, reddish-orange with some pink banding and mottling, very fine- to fine-grained, argillaceous, evenly-bedded with occasional cross-laminated beds, cemented with calcium carbonate and ferric oxide; surface markings include rain pits, worm borings(?), and ripple marks; weathers in irregular surfaces	113
Sandstone, with intercalated lenses of lime-pellet conglomerate; fine- to medium-grained, reddish-orange to reddish-brown, evenly bedded, with occasional cross-laminated beds, abundant ripple marks, cemented with ferric oxide and calcium carbonate; weathers in irregular ledges .	23
Sandstone interbedded with lenses of lime-pellet conglomerate; fine- to coarse-grained, sub-arkosic, reddish-brown cross-laminated beds intercalated with evenly bedded strata; thin-bedded, cemented with calcium carbonate; weathers in irregular ledges	9
Sandstone, interbedded with siltstone, very fine- to fine-grained; argillaceous, reddish-orange, evenly bedded, thin-bedded, cemented with calcium carbonate and ferric oxide, abundant ripple marks and deoxidation spots; weathers in regular slopes	136
Sandstone, interbedded with siltstone and occasional lime-pellet conglomerate beds; argillaceous, very fine- to fine-grained, reddish-brown, evenly bedded strata with occasional cross-laminated beds, thin- to medium-bedded; cemented with ferric oxide and calcium carbonate; abundant deoxidation spots and ripple marks; weathers in rolling slopes	109
Conglomerate, grayish-pink, coarse-grained arkosic matrix with cobbles and pebbles of quartzite and gneiss, argillaceous, evenly to irregularly bedded, thin- to medium-bedded, cemented with calcium carbonate; weathers in irregular ledges .	3

Section of Permian rocks (continued)

	Thickness (feet)
Unconformity.	
Precambrian system:	
Gneisses and quartzites. Amount of relief on Precambrian erosion surface not determined. Thickness of exposed section not measured.	
Total thickness of strata measured	1,532

The upper member of the Yeso formation, the San Ysidro member, is composed of evenly bedded, fine-grained clayey sandstone and siltstone from 250 to 350 feet thick. The sandstone and siltstone are similar in composition to the Meseta Blanca sandstone member but are composed of rather poorly sorted materials. The sandstone is predominantly red or pinkish red, with thinner yellow or white layers. The interbedded siltstone is orange to red. The lower part of the San Ysidro member usually contains two or three beds of limestone and rarely a fourth bed. The lowermost limestone commonly is 40 to 50 feet above the base of the member. The beds of limestone range in thickness from 6 to 12 feet, are bluish gray, and are thinly bedded. The second limestone above the base usually is somewhat fossiliferous; a few bryozoa and brachiopods have been found in this limestone. The beds of limestone are separated by beds of varicolored siltstone, sandstone, and mudstone, usually 40 or 50 feet thick, that are predominantly orange brown or red.

The San Ysidro member grades upward from the rather poorly sorted, predominantly red sandstone and siltstone into white to buff-colored well-sorted sandstone of the overlying Glorieta sandstone. Choosing of the contact must be arbitrary in many places and may result in considerable difference in estimated or measured thickness of both the Yeso and Glorieta formations. A section measured by R. E. Smith near the mouth of Bluewater Canyon included 32 feet of beds assigned to the upper part of the Yeso formation. The measured section is given on page 24.

The term "Yeso," the Spanish word for gypsum, was applied to the Yeso formation because of the gypsiferous strata at the type locality in Socorro County, N. Mex., and at many other places throughout the region. Only moderate quantities of gypsum have been observed in outcrops in the Grants-Bluewater area. Streaks and thin layers of gypsum interbedded with the siltstone have been logged in some of the test holes and wells in the area, and some of the strata in the upper member of the Yeso are cemented with gypsum in some localities.

The Yeso formation yields water to stock and domestic wells and springs and to a few irrigation wells. (See tables 4 and 5.)

Glorieta Sandstone

The Glorieta sandstone, formerly considered to be a member of the San Andres formation, recently has been raised to formational rank (Dane and Bachman, 1957). The Glorieta is well exposed in Bluewater Canyon, Zuni Canyon, and several other canyons along the northwest flank of the Zuni Mountains. The unit is exposed extensively on some of the higher slopes south of Zuni Canyon. The sandstone, containing flecks of limonite in many places, usually is well sorted, medium grained, white to light gray or buff, and may be alternately crossbedded and evenly bedded. Weathered exposures usually are yellow to light brown. The lower part of the formation usually is soft and friable; the upper strata may be very hard in places because of cementation with silica.

The Glorieta sandstone ranges in thickness from 125 to 300 feet. The thickness of the formation is difficult to determine in many places because of a gradational contact with the underlying Yeso formation. The contact between the Glorieta and the overlying San Andres limestone also is gradational in places, particularly in the southern part of the area where a zone of alternating beds of sandstone and limestone form the contact.

The Glorieta sandstone is 150 feet thick in an exposure in the south wall of Bluewater Canyon, a quarter of a mile above the mouth of the canyon, as measured by R. E. Smith of the Geological Survey. A total thickness of 346 feet of strata of the Yeso, Glorieta, San Andres, and Chinle formations (fig. 6) was measured by Smith, as follows.

Section measured by R. E. Smith, a quarter of a mile above mouth of Bluewater Canyon, on the south wall, in SW$\frac{1}{4}$ sec. 5, T. 12 N., R. 11 W., Valencia County, N. Mex.

		Thickness (feet)
Triassic system:		
Shinarump(?) conglomerate (lower Chinle formation of this report)		17.5
Sandstone, conglomeratic, dark-red	17.5	
Permian system:		
San Andres limestone		145.5
Upper limestone member (97.5 feet)		
Concealed	17.5	
Limestone, light-gray on fresh surface, gray on weathered surface, massive, compact	80	
Middle sandstone member (18.2 feet)		
Sandstone, lower 4 feet friable, top 12.7 feet partly concealed	16.7	
Concealed	1.5	
Lower limestone member (29.8 feet)		
Limestone, as above. Top portion of this unit partly concealed	5.8	
Sandstone, light-yellow on fresh surface, forms recess, thickness varies	.6	
Limestone, as above	4.4	

Section a quarter of a mile above mouth of Bluewater Canyon (continued)

		Thickness (feet)
Permian system (continued)		
San Andres limestone (continued)		
Lower limestone member (29.8 feet) (continued)		
Sandstone. Top 0.5 foot light-gray on fresh surface, overlying a well-cemented medium- to fine-grained layer with a light-pink cast. Layer of argillaceous sandstone with greenish-yellow tint about 0.3 foot above bottom of bed	3.8	
Limestone, as above	15.2	
Glorieta sandstone		150.8
Sandstone, white on fresh surface, resistant to weathering. Top 0.2 foot consists of a more friable seam with undulating upper and lower surfaces	1.2	
Siltstone, argillaceous, gray, poorly cemented	2.0	
Limestone, light-purple on fresh surface. Undulating upper and lower surfaces	.1	
Siltstone, medium-grained in upper half. Olive-green in lower half. Argillaceous	1.0	
The above three beds form a recess or talus slope.		
Sandstone, light-yellow on fresh surface, medium-grained, cliff-forming	76	
Sandstone, red on fresh surface, massive, medium-grained	15.1	
Siltstone. Upper part dull yellow and contains a few concretions which are iron stained and have a limonitic center; lower part argillaceous and olive-green. Red, well-cemented sandstone about 0.04 foot thick occurs 0.04 foot above base of bed	1.4	
Sandstone, light-pink on fresh surface, massive, resistant to fairly soft	8.1	
Sandstone, light-yellow to pink on fresh surface, poorly cemented	2.0	
Sandstone, light-pink, massive	3.5	
Sandstone, upper and lower parts greenish-yellow; middle part mottled pink and dirty white and more resistant to weathering	3.5	
Sandstone, medium-fine-grained. Middle portion evenly bedded and well cemented. Middle portion and top 1 foot pink on fresh surface, rest of bed light yellow on fresh surface	11.3	
Sandstone, dirty-white to yellow on fresh surface, poorly cemented	2.8	
Siltstone, argillaceous, olive-green, poorly cemented	1.0	

Section a quarter of a mile above mouth of Bluewater Canyon (continued)

		Thickness (feet)
Permian system (continued)		
Glorieta sandstone (continued)		
Sandstone, light-yellow on fresh surface, fine-grained, resistant to weathering	3.0	
Sandstone, dirty-white on fresh surface, fine-grained, poorly cemented, forms recess	1.2	
Sandstone, light-yellow on fresh surface, fine-grained, massive	6.5	
Sandstone, light-yellow to pink, poorly cemented; in places forms a deep recess	1.5	
Sandstone, light-yellow on fresh surface, massive, medium-fine-grained	9.6	
Yeso formation (only top part exposed)		32.4
Sandstone, alternate well- and poorly-cemented layers, medium-fine-grained. Well-cemented massive layers. Light-yellow layer at top of beds	10.4	
Sandstone, argillaceous, dark-red, poorly cemented	2.0	
Sandstone, red-yellow toward top, fine-grained, resistant to weathering, massive	2.2	
Sandstone, dark-red, fine-grained, poorly cemented.		
Powdery white streaks toward top	1.2	
Sandstone, pink, poorly cemented	1.1	
Siltstone, argillaceous, dark-red	.8	
Sandstone. Top 0.07 foot white and calcareous, middle 0.2 foot dark red, basal 0.03 foot white .	.3	
Sandstone, red, well-cemented, evenly bedded	1.8	
Sandstone, evenly bedded. Generally less resistant than overlying and underlying beds. Top 0.4 foot white, middle 1.0 foot red, and basal 0.2 foot white; these thicknesses vary	1.6	
Sandstone, light-yellow to almost white on fresh surface, medium-fine-grained, resistant to weathering, crossbedded	5.8	
Sandstone, red, calcareous, medium-grained, crossbedded.		
Some portions light yellow and more resistant to weathering. Base concealed, exposed thickness	5.2	
Total thickness exposed		346.2

The Glorieta sandstone and San Andres limestone together constitute a single aquifer. Generally, however, the Glorieta yields less water than the San Andres. The Glorieta in most places yields adequate quantities of water for irrigation, industrial, and municipal supplies. (See table 4.)

San Andres Limestone

The San Andres limestone is exposed widely in the canyon walls and on the dip slopes along the northeast flank of the Zuni Mountains and along the edge of the valley southwest of the railroad between Grants and Bluewater. The formation is well exposed in Bluewater Canyon between Bluewater Dam and the mouth of the canyon, and along the road through Zuni Canyon.

The San Andres may be divided into three units in the Grants-Bluewater area. The lower unit is composed of a massive bluish-gray limestone that is somewhat dolomitic, sandy in the basal part, and sparsely fossiliferous. The basal part of this unit in places consists of interbedded sandstone and limestone. The limestone ranges in thickness from 20 to 40 feet. A light-gray to yellowish-buff sandstone, which ranges in thickness from 15 to 30 feet, overlies the lower limestone. The sandstone is medium grained, fairly well sorted, friable, locally crossbedded, and in part cemented with calcium carbonate. The upper unit of the San Andres is composed of massive, gray, fossiliferous limestone that ranges in thickness from 60 to 100 feet. The upper part of this limestone unit is cherty in many places and may be pink. In some places, as in the area northeast of Bluewater, the upper part of the unit is very sandy and locally may be classified as a sandy limestone or calcareous sandstone. The log of a well in the SW$\frac{1}{4}$SW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 24, T. 12 N., R. 11 W., indicates that the upper 32 feet of the formation is a calcareous sandstone. The log, which is based on descriptions of cores from the lower part of the test hole, is given in the following table. Logs of other wells that tap the San Andres are given in table 6.

Log of test hole 12.11.24.233
(The Anaconda Co. Water Well No. 2)

Drilled with hydraulic-rotary drill from the surface to 143 feet, and with core drill from 143 feet to the bottom. Descriptions of samples above 143 feet not available; descriptions of samples below 143 feet are generalized from core log.

	Thickness (feet)	Depth (feet)
Quaternary system:		
Valley fill:		
Basalt	85	85
Alluvial fill; conglomerate at base of basalt	10	95
Triassic system:		
Chinle formation:		
No description given	48	143
Shale, variegated dark-purple to blue, locally yellowish-brown; iron oxide stains. Very broken	11	154
Sandstone, clear subrounded quartz grains with highly calcareous cementation; contains irregular partings of green and purple shale, occasional fragments of dark-colored chert, and some mica along bedding planes	7	161

Log of test hole 12.11.24.233 (continued)

	Thickness (feet)	Depth (feet)
Triassic system (continued)		
Chinle formation (continued)		
Shale, bluish-maroon, dark-purple, and bluish-green, badly broken, a few dark-colored chert pebbles and quartz pebbles as much as 3/4-inch in diameter	19	180
Sandstone, medium-gray, fine- to medium-grained, locally calcareous, micaceous	9	189
Shale, green, with interbedded sandstone as above; more shaly in lower part	7	196
Shale, bluish-green, locally sandy	22	218
Shale, very sandy, dark-maroon, transitional to shaly sandstone in lower part	8	226
Sandstone, medium-grained, clayey, light- to dark-maroon, locally slightly calcareous, pebbly appearance	15	241
Shale, dark-maroon, massive, slightly calcareous, sandy in lower part, pale-green in basal 1 foot	21	262
Permian system:		
San Andres limestone:		
Upper member:		
Sandstone, highly calcareous, medium- to fine-grained, grayish-white, massive, pyrite inclusions; thin interbedded light-green sandy shale. Lower 2 feet is brown and tan, heavily iron-stained, appears to be a water course(?)	19	281
Sandstone, highly calcareous, buff, massive, with local areas of very sandy, slightly iron-stained vuggy limestone	13	294
Limestone, light-buff-gray, massive, fossiliferous, extensive alteration in upper part, cavities reported by driller at 295-297 feet; lower part only slightly altered	24	318
Middle member:		
Sandstone, medium-grained, clear, well-rounded quartz grains, light-buff, massive, tiny specks of iron oxide disseminated throughout, uniformly calcareous, locally fossiliferous	17	335
Lower member:		
Limestone, variegated brown, buff, and gray, generally slightly to moderately altered, iron oxide staining; cavities as much as 0.1 foot in diameter	20	355

Log of test hole 12.11.24.233 (continued)

	Thickness (feet)	Depth (feet)
Permian system (continued)		
San Andres limestone (continued)		
Lower member (continued)		
Limestone, variegated brown, buff, and gray, tight, slightly altered	9	364
Glorieta sandstone:		
Sandstone, medium-grained, clear rounded quartz sand, massive, homogeneous, upper 3 feet slightly calcareous	22	386
Sandstone, limy, with interbedded sandy limestone; many irregular seams of dark-blue siltstone as much as 1 inch thick	29	415
Sandstone, medium-grained, light-buff, massive, slightly calcareous, well-sorted, slightly ferruginous	11	426
Sandstone, as above, with irregular seams of blue siltstone in sandstone at 426-427 and 436-437 feet	25	451 T.D.

The San Andres limestone in the Grants-Bluewater area averages 110 feet in thickness. The thickness, however, differs throughout the area and may range from 80 to 150 feet. The formation is 145 feet thick near the mouth of Bluewater Canyon and is 102 feet thick in the industrial well 12.11.24.233.

The San Andres limestone is the uppermost formation of Permian age exposed in the Grants-Bluewater area. After deposition of the San Andres, the region was uplifted and subjected to a long period of erosion before deposition of strata of Late Triassic age. During this erosion period, a karst topography having a relief of more than 100 feet was developed on the San Andres erosion surface (fig. 7). The entire formation was removed by erosion in places where rocks of Late Triassic age now lie directly on the Glorieta sandstone. Sinkholes that developed in the San Andres limestone during this period of erosion were filled later with sediments of Triassic age, or filled still later with sand, gravel, and silt.

The San Andres limestone is the major aquifer in the area. Well-connected cavernous zones and solution channels have developed in the formation, and the transmissibility of the aquifer, therefore, is great in most places. The San Andres yields adequate quantities of water for irrigation, industrial, and municipal supplies. (See table 4.)

Triassic System

Sedimentary rocks of Triassic age, having a total thickness of 1,500 to 1,800 feet, are exposed widely in the Grants-Bluewater area. The rocks of Triassic age overlie rocks of Permian age in scattered exposures along

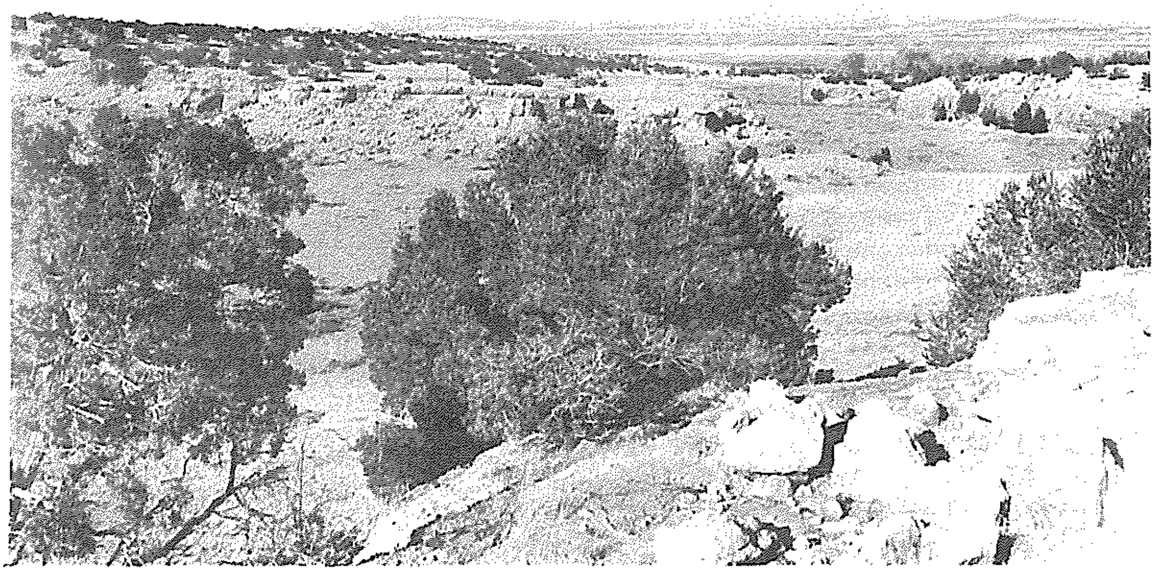


FIGURE 7. -- Modified karst topography developed on the San Andres limestone. View northward from the SW$\frac{1}{4}$ sec. 22, T. 12 N., R. 11 W., about half a mile southeast of Bluewater, Valencia County, N. Mex. Flat-topped topographic feature on skyline in background is Haystack Mountain, which is capped by the Dakota sandstone.

the northeast flank of the Zuni Mountains and underlie much of the area from Bluewater Creek northward to the railroad. Rocks of Triassic age are exposed extensively in the area northeast of Bluewater and in places along the base of the cliffs that bound the northern and eastern sides of the area. Rocks of Triassic age underlie the alluvium throughout much of the Grants-Bluewater Valley northwest of Grants and much of Malpais Valley south and southeast of Grants.

The lowermost strata of Triassic age were deposited as somewhat discontinuous deposits of channel fill on the irregular surface of the San Andres limestone. These strata were assigned by Darton (1928a) to the Moenkopi formation of Early Triassic age. Later work (McKee, 1951b; Cooley, 1957), however, indicates that Moenkopi deposits probably do not extend as far east as the Grants-Bluewater area and that these deposits are somewhat younger than the Moenkopi formation in northeastern Arizona. According to Cooley (unpublished Master's Thesis, University of Arizona, 1957), the Chinle formation overlies the channel-fill deposits unconformably. In this report, however, these channel-fill and associated deposits are included, for convenience, in the Chinle formation of Late Triassic age. The strata of Triassic age are therefore assigned, in ascending order, to the Chinle formation and the Wingate sandstone.

Chinle Formation

The Chinle formation was described originally by Gregory (1917) from exposures in Chinle Wash on the Navajo Indian Reservation in Arizona. The formation has been examined and variously defined by others (Cooley, 1957; Harshbarger, Repenning, and Irwin, 1957; Smith, 1954, 1957; and others) in the Zuni Mountains and adjacent areas. Several other reports containing descriptions of the formation are in preparation. Although a complex and diverse nomenclature for members of the formation has been used by various writers, a simplified nomenclature and brief description of the Chinle formation is presented here. The reader is referred to publications listed at the end of this report for more detailed descriptions of the formation and for discussions of the stratigraphic problems involved.

The Chinle formation is 1,400 to 1,600 feet thick in the Grants-Bluewater area. The strata, which were deposited in a continental environment, consist principally of varicolored clay and siltstone, interbedded silty sandstone, and some coarse-grained to conglomeratic sandstone. (See table 6.) Gypsum crystals are common on weathered exposures.

The Chinle formation may be divided conveniently into three units in the Grants-Bluewater area. The lower unit is composed of reddish-brown to purple and light-gray to white silty sandstone and interbedded varicolored siltstone and mudstone. The unit contains several beds of coarse-grained to conglomeratic sandstone, particularly in the basal part. The upper part of the unit contains abundant fragments of petrified wood in many places. The unit ranges in thickness from 400 to 500 feet.

The middle unit of the Chinle formation is composed of poorly sorted crossbedded sandstone, conglomeratic sandstone, conglomerate, and interbedded thin lenses of siltstone and mudstone. The strata usually are light orange to light gray, medium to thick bedded, and moderately hard. Cobbles as large as 6 inches in length have been found in some of the coarser conglomerate. As this middle unit intertongues with both the upper and lower units of the Chinle, the thickness may differ considerably within relatively short lateral distances. The thickness may range from 60 to 200 feet, but in most places it is 100 feet or more. Locally, the middle unit contains many logs of petrified wood.

The upper unit of the Chinle is composed of a variety of rock types but is predominantly siltstone and mudstone and some interbedded fine-to medium-grained sandstone. The upper part of the unit contains numerous layers and lenses of nodular fine-grained limestone. The beds of siltstone and mudstone usually are reddish brown, thinly bedded, and somewhat silty. The limestone lenses and nodules may be brown, red, purple, or gray, and they commonly are interbedded with silty to sandy calcareous mudstone. The upper unit is 900 to 1,000 feet thick. The upper 300 feet of the unit contains most of the limy strata. The contact with the overlying Wingate formation usually is marked by a slight erosional unconformity having a local relief of a few inches to a few feet.

Sandstone and silty sandstone units in the Chinle formation yield adequate supplies of water for stock and domestic use. The sandstone and conglomeratic sandstone in the lower part of the formation in some places yield water to irrigation wells. (See table 4.)

Wingate Sandstone

The Wingate sandstone, as described originally by Dutton (1885) at the type locality near the Wingate railroad station, McKinley County, N. Mex., was composed of all the beds of sandstone and associated strata between the top of the Chinle formation and the base of the Todilto limestone and was considered to be of Jurassic age. Later investigations indicated a need for revision of the nomenclature pertaining to this formation. Harshbarger, Repenning, and Jackson (1957) restricted the formation to the lower 359 feet of the section formerly included in the Wingate sandstone at the type locality and assigned it to the Upper Triassic series. The upper bed of sandstone at Dutton's type locality now is recognized as being the Entrada sandstone of Late Jurassic age.

The Wingate sandstone is composed of light-reddish-brown to orange sandstone. The sandstone is thickly bedded to massive, crossbedded, and of eolian origin. It ranges in thickness from 80 to 120 feet in the area. The Wingate was reported to be 114 feet thick in a measured section in the SW corner sec. 9, T. 12 N., R. 9 W. (R. E. Thaden, 1957, written communication).

The Wingate sandstone has been removed by erosion from the major part of the area and is present only along the northeastern and eastern margins of the area. The outcrops of the Wingate are not in favorable locations for recharge. Only one well (9.9.5.214) in the area is believed to tap this formation. The Wingate sandstone should, however, yield adequate supplies of water to wells for stock and domestic use in areas where it is saturated.

Jurassic System

Sedimentary strata of Middle and Late Jurassic ages are widely exposed in the cliffs and along the slopes bounding the northeastern and eastern sides of the Grants-Bluewater and Malpais Valleys. These strata, which are about 1,000 feet thick, are composed of alternating units of shale and sandstone and one limestone formation. They are assigned, in ascending order, to the San Rafael group and the Morrison formation.

The rocks of Jurassic age and overlying rocks of Cretaceous and Tertiary ages are relatively minor aquifers in the Grants-Bluewater area. The descriptions of these strata, therefore, are brief and generalized. More detailed descriptions are available in the publications listed at the end of this report. Also, investigations now in progress by the Geological Survey will provide much more detailed descriptions of these rocks.

San Rafael Group

The San Rafael group in the Grants-Bluewater area includes, in ascending order, the Entrada sandstone, Todilto limestone, Summerville formation, and Bluff sandstone. This group of formations is shown as a unit on the geologic map (pl. 1) of the area.

Little is known of the water-bearing properties of the formations in the San Rafael group. Well 9.9.3.331, which probably taps the Entrada sandstone, is reported to yield 20 gpm of water suitable for stock use. Sandstone in the Summerville formation in favorable localities should be capable of yielding adequate supplies of water to wells for stock and domestic use. Stock and domestic well 9.9.29.224 probably taps the Bluff sandstone.

The lower part of the Entrada sandstone is composed of fine-grained, massive, reddish-brown, silty sandstone and minor amounts of mudstone. The upper part consists of medium- to coarse-grained, crossbedded, massive, light-reddish-brown to orange sandstone. Locally, the upper part of the sandstone is very calcareous and grades into the overlying limestone. The Entrada sandstone is 200 to 250 feet thick in the northern and northeastern parts of the area; but it thins somewhat, to 175 feet or less, in the southeastern part.

The Todilto limestone is a thin-bedded, platy, dark-gray, dense limestone that contains thin partings of greenish-gray clay or siltstone. Locally, the limestone is gypsiferous and, in some places, thin layers of siltstone and gypsiferous sandstone are interbedded with the limestone. The formation ranges in thickness from 10 to 30 feet and commonly is 12 to 15 feet thick. Uranium deposits of great value have been discovered in the Todilto limestone northwest, north, and northeast of Grants.

The Summerville formation is composed predominantly of reddish-brown, fine-grained sandstone and interstratified white to red siltstone. The strata are flat to wavy bedded. Some small-scale crossbedding is present, especially in the upper part of the formation. The basal part of the formation locally contains lenses of limestone and silty limestone. The Summerville formation generally ranges in thickness from 75 to 200 feet.

The Bluff sandstone consists predominantly of light-gray to yellowish-gray or light-brown, fine- to medium-grained, massive, crossbedded sandstone and silty sandstone, that commonly weathers into smooth, rounded exposures. The Bluff sandstone is 175 to 200 feet thick throughout the area.

Morrison Formation

The Morrison formation, which is shown as a unit on the geologic map (pl. 1), consists, in ascending order, of the Recapture, Westwater Canyon, and Brushy Basin members. The Morrison varies considerably in thickness in the Grants-Bluewater area because of erosion during Early Cretaceous time, prior to deposition of the overlying Dakota sandstone. The Morrison in the northern and northeastern parts of the area generally ranges in thickness from 300 to 500 feet. In the southeastern part of the area, however, the Dakota overlies successively lower beds southward. Either the entire Morrison formation has been removed by pre-Dakota erosion along the east side of Malpais Valley, at a point 3 miles southwest of U. S. Highway 66, or its lithology changes abruptly; southward from this area the Dakota overlies the San Rafael group or similar rocks.

No wells are known to tap the Morrison formation in the area. A few miles to the north in McKinley County, however, the Westwater Canyon member of the Morrison yields adequate quantities of water for stock and domestic supplies.

The Recapture member of the Morrison formation is composed of dark-reddish-brown claystone and siltstone interbedded with light-gray, very fine-grained, poorly sorted, crossbedded sandstone. The beds of claystone and siltstone are predominant in the lower part of the section, and the beds of sandstone are predominant in the upper part. The beds of sandstone commonly are 3 to 6 feet thick, and the siltstone beds commonly are 1 to 3 feet thick. The Recapture member intertongues with the overlying Westwater Canyon member, resulting in considerable variation in thickness of the Recapture in various places. The Recapture generally ranges in thickness from 75 to 200 feet in the area.

The Westwater Canyon member of the Morrison, a thick sandstone unit, overlies the Recapture member. The Westwater Canyon member is composed of poorly sorted, very fine- to coarse-grained, grayish-orange to grayish-pink, massive, crossbedded sandstone. The lower part of the sandstone locally is calcareous, and in some places the sandstone contains mudstone and siltstone partings and mud pods near the base. The Westwater Canyon member intertongues with the underlying Recapture member and the overlying Brushy Basin member; consequently, the thickness of the Westwater Canyon member varies widely. The Westwater Canyon member along the outcrop generally ranges in thickness from 110 feet near the northwest corner of the Grants-Bluewater area to 60 feet in the eastern part.

Valuable deposits of uranium ores have been discovered in the Westwater Canyon member in exposures along the north and northeast sides of the Grants-Bluewater Valley and on the north side of the Grants Ridges, north of Grants. Major uranium deposits were discovered in this formation north of and adjacent to the Grants-Bluewater area, in the vicinity of Ambrosia Lake.

The upper member of the Morrison formation, the Brushy Basin member, in places is composed of light-greenish-gray or yellowish-gray, locally calcareous claystone and siltstone and intercalated lenses of yellowish-gray to yellowish-brown, medium- to coarse-grained sandstone. The lithology of the member varies considerably along the outcrop. The sandstone facies in places may predominate. The member appears to thicken to the northeast. The Brushy Basin member commonly is 150 to 200 feet thick; however, it is only about 50 feet thick near Thoreau, N. Mex., northwest of the Grants-Bluewater area. The entire member has been removed from the southeastern part of the area by post-Morrison erosion.

Cretaceous System

Strata of Early(?) and Late Cretaceous ages are exposed along the northern, northeastern, and eastern margins of the Grants-Bluewater area. These strata, which unconformably overlie slightly beveled strata of Late Jurassic age, consist of a thick sequence of shale and sandstone. Parts of the sequence contain interbedded coal seams, some of which are of considerable economic value in adjacent areas. The Cretaceous section exposed in the area is between 1,000 and 1,500 feet thick. The sequence consists, in ascending order, of the Dakota sandstone, Mancos shale, and Mesaverde group. Stratigraphic relations of these geologic units are complex. The strata were deposited under alternating continental and marine environments. The Dakota sandstone was deposited in a continental environment at the margin of an advancing sea. It is overlain by beds of marine shale of the Mancos. The Mancos shale is overlain by the Mesaverde group, which is composed of alternating beds of sandstone, siltstone, and claystone, and some beds of carbonaceous shale and coal that were deposited in a continental environment at the margin of a retreating sea. Deposition of the marine Mancos shale continued in the area to the northeast, where it intertongues with some parts of the Mesaverde group. Thus, the marine shale of the Mancos intertongues with the Dakota sandstone below and with various formations in the Mesaverde group above. The lowermost sandstone above the unconformable contact with the rocks of Jurassic age is designated as the Dakota sandstone. Therefore, because of oscillations in the shoreline of the advancing Cretaceous sea, the age of the Dakota sandstone may differ slightly in places.

Dakota Sandstone

The Dakota sandstone in the Grants-Bluewater area is composed of massive, yellowish-buff or yellowish-orange to light-brown, limonitic, crossbedded sandstone. The lower part of the sandstone commonly is coarse grained and locally conglomeratic; the upper part is somewhat finer grained than the lower part. A bed of carbonaceous shale and interbedded medium-grained clayey sandstone underlies the principal bed of sandstone in the northern part of the area. The Dakota in places consists of two thick beds of sandstone that are separated by beds of carbonaceous siltstone and shale, 15 to 20 feet thick, that contain seams of coal locally. The thickness of the Dakota sandstone varies in different places because of intertonguing with the overlying Mancos shale; however, in much of the area it ranges in thickness from 70 to 80 feet. The Dakota thins markedly in the southeastern part of the Grants-Bluewater area, southward from U. S. Highway 66, and is only a few feet thick at the southern boundary of the area.

No wells are known to tap the Dakota sandstone in the area. Wells to the north in McKinley County, however, obtain adequate quantities of water for stock and domestic supplies from this formation.

Mancos Shale

The Mancos shale is composed of predominantly dark-gray, platy, calcareous marine shale that weathers to a light yellowish gray. The Mancos ranges in thickness from 700 to 800 feet; the lower 300 to 350 feet of the shale contains three or four thickly bedded to massive beds of sandstone that closely resemble the sandstone of the Dakota. These beds of sandstone generally range in thickness from 30 to 75 feet. The upper part of the shale in places contains a few thin fossiliferous calcareous beds of sandstone. The lower sandstone beds of the Mancos in many places are very fossiliferous.

The formation does not yield water in significant quantities to wells in the area.

Mesaverde Group

The Mesaverde group in the Grants-Bluewater area includes, in ascending order, only the Gallup sandstone and the Crevasse Canyon formation. The Mesaverde group is not subdivided on the geologic map (pl. 1).

The Gallup sandstone in the Grants-Bluewater area intertongues with the Mancos shale. Two thin beds of sandstone, which apparently are in the upper part of the Mancos shale, coalesce with the main body of the Gallup sandstone farther west toward Gallup. A massive bed of sandstone 65 feet thick is the principal unit of the Gallup sandstone in the Grants-Bluewater area. A thin transitional zone of interbedded thin sandstone and shale generally is present at the base of the sandstone.

No wells in the Grants-Bluewater area are known to tap the Mesaverde group, but several artesian wells north of San Mateo, in southeastern McKinley County, tap a bed of sandstone in the Mesaverde group. The water is used for stock and domestic supplies.

The Crevasse Canyon formation in the Grants-Bluewater area is divided into two members, in ascending order, the Dilco coal member and the Dalton sandstone member. The Dilco coal member is about 100 feet thick and consists of continental shale, sandstone, and local beds of coal. The upper part consists of massive sandstone about 50 feet thick. This sandstone is overlain by the Mulatto tongue of the Mancos shale, which is about 250 feet thick and consists of light-tan sandy marine shale, containing some intercalated thin beds of sandstone. The Dalton sandstone member overlies the Mulatto tongue and is a massive crossbedded sandstone that ranges in thickness from 100 to 125 feet. The Dalton sandstone probably is the uppermost member of the Crevasse Canyon formation that is exposed in the Grants-Bluewater area.

Tertiary System

Extrusive Rocks

Basaltic lava flows of late Tertiary age cap the Grants Ridges and La Jara and Horace Mesas, north, northeast, and east, respectively, of Grants. These flows, which were extruded from volcanic vents on the mesas, were deposited on beveled and tilted strata of Triassic, Jurassic, and Cretaceous ages. One of the volcanic vents, on the northeastern mesa of the Grants Ridges, has been exposed by erosion. The flows were deposited on an erosional surface that lies about 750 feet above the present valley floor. The basalt flows at the time of deposition probably were connected to form a continuous sheet of basalt. Subsequent erosion has removed much of the basalt, leaving only remnants capping the high mesas. The basalt was deposited by several different flows, which generally ranged in thickness from 30 to 80 feet; the total thickness ranges from 200 to 300 feet in exposures along the edges of the mesas.

Many springs issue from the basalt along the margin of Horace and La Jara Mesas and at various favorable topographic positions on the mesas. The springs provide water for stock and domestic use at work camps during the summer.

Quaternary System

Deposits of Quaternary age in the Grants-Bluewater area consist of alluvium, landslide and talus material, dune sand, and basaltic lava flows. The deposits of landslide and talus material and the dune sand are areally small and are included with the alluvial deposits in this report.

Alluvium

After the deposition of the late Tertiary basalt flows and the development of the late Tertiary and early Pleistocene(?) cinder cones, the stream courses in the main valleys of the Grants-Bluewater area were eroded to depths of 150 to 200 feet or more below the altitude of the present land surface. Alluvial deposits of silt, sand, and gravel then were deposited in and along the stream courses. These deposits attained a maximum thickness of 30 or more feet and covered most of the valley floor. Basaltic lava flows then filled parts of the valleys. Alluvial deposits continued to accumulate in the valleys adjacent to the basalt flows. Apparently, however, the alluvium accumulated in depths sufficient to cover the older basalt flows only in a few local areas before younger basaltic flows were extruded. Deposition of alluvium apparently has continued to the present time. In general, the basal part of the alluvium contains the greatest proportion of sand and gravel. The upper part of the alluvium is composed predominantly of silt and fine sand. The alluvium, together with the interbedded basalt flows in those areas where they are present, generally ranges in thickness from 100 to 140 feet in the area between Bluewater and Grants. (See table 6.)

Basalt

Four basalt flows from at least three different sources can be identified in the Grants-Bluewater area. Three of these flows were designated by Nichols (1934, 1936) as the Laguna, Bluewater, and McCartys flows. The Suwanee flow of Nichols is 40 miles east of the Grants-Bluewater area. The fourth flow in the Grants-Bluewater area, which was not treated by Nichols, is designated the Zuni Canyon basalt flow in this report. The areas of outcrop of the four flows are shown on the geologic map.

The Laguna basalt flow underlies most of Malpais Valley and most of that portion of the Rio San Jose valley south of U. S. Highway 66 from the vicinity of Grants southeastward beyond the eastern boundary of the report area. This flow originated at volcanic vents in the area adjacent to the southeast end of the Zuni Mountains and south of the area included in this report. The lava flowed eastward around the end of the uplift and then northward down Malpais Valley. It covered most of the valley floor on reaching the Rio San Jose and flowed up the valley at least as far as Grants. The lava also flowed down the Rio San Jose valley and beyond the eastern boundary of the area included in this report. The Laguna flow is buried beneath the Zuni Canyon basalt flow near Grants and beneath the McCartys basalt flow along the eastern margin of Malpais Valley. Two basalt flows in Malpais Valley, intermediate in age between the Laguna and McCartys basalt flows, terminate 3 or 4 miles north of the southern boundary of the area. These flows are included with the Laguna basalt flow on the geologic map.

The Bluewater basalt flow originated at El Tintero crater, a volcanic vent in southern McKinley County 5 miles north-northeast of the Bluewater railway station. This basalt flow covered a large part of the Grants-Bluewater Valley. The lava flowed generally southeastward down the valley to the vicinity of Grants. The basalt in the valley is exposed as far south as Toltec Siding, a few miles northwest of Grants, and it has been penetrated beneath the alluvium in wells south of the outcrop area. The Bluewater basalt flow probably coalesced with the Laguna flow near Grants.

The Laguna and Bluewater basalt flows appear to be composed of several flows in which layers of vesicular and dense basalt alternate. The greatest recorded thickness of basalt in the area, 197 feet, was penetrated in a deep oil test a few miles southeast of Grants in the NE$\frac{1}{4}$ sec. 21, T. 10 N., R. 9 W. A core test about a mile northeast of Bluewater in the NE$\frac{1}{4}$ sec. 14, T. 12 N., R. 11 W., penetrated 117 feet of the Bluewater basalt flow, and a core test in Malpais Valley 8 miles south of Grants in the E$\frac{1}{2}$ sec. 2, T. 9 N., R. 10 W., penetrated 58 feet of the Laguna basalt flow. The logs of these core tests follow.

9.10.2 ($E\frac{1}{2}$ of sec.). Core test, U. S. Corps of Engineers

	Thickness (feet)	Depth (feet)
Quaternary system:		
Alluvium and basalt:		
Soil, sandy to silty, light-brown	16	16
Soil, clayey; contains 40 percent gravel composed of basalt, granite, and limestone	2.2	18.2
Basalt, vesicular	7.8	26.0
Basalt, dense	2.1	28.1
Basalt, vesicular	2.6	30.7
Basalt, dense	13.1	43.8
Basalt, vesicular	5.5	49.3
Basalt, dense	3.6	52.9
Basalt, vesicular, iron-stained	3.0	55.9
Basalt, vesicular	12.6	68.5
Basalt, dense; somewhat vesicular in lower 1 foot	6.7	75.2
Basalt, vesicular	1.3	76.5
Core lost; probably clay fill	.3	76.8
Limestone boulder; white, dense, fossiliferous ...	.6	77.4
Silty clay, gray, friable	1.2	78.6
Clay, red, sandy	3.7	82.3
Apparently alternating zones of sand and clay	18.3	100.6

12.11.14.213 Duane Berryhill (Core test, U. S. Corps of Engineers)

Quaternary system:		
Alluvium and basalt:		
Topsoil, sandy and silty, brown; some vesicular basalt fragments	2	2
Soil, sandy, some vesicular basalt fragments	1.3	3.3
Basalt, vesicular, increasingly fewer vesicles to none at 9.8 feet	6.5	9.8
Basalt, dense	20.7	30.5
Basalt, vesicular	6.5	37.0
Basalt, dense	3.8	40.8
Basalt, vesicular; vesicles contain brown silt ...	7.2	48.0
Basalt, dense	3.0	51.0
Basalt, vesicular, very porous; some silt in vesicles	20.3	71.3
Basalt, vesicular; vesicles decrease to zero at 75.0 feet	3.7	75.0
Basalt, dense; a few vesicles from 85.5 to 90.6 feet with a small amount of silt in small vesicles	20.0	95.0
Basalt, vesicular; small amount of silt in vesicles. Less vesicular from 100.7 to 103.5 feet. No vesicles at 103.5 feet	8.5	103.5
Basalt, dense	11.5	115.0
Basalt, very vesicular	1.8	116.8
Sand and gravel and 1 inch of red clay (recovered by drive-core method)	4.7	121.5
Sand and gravel	8.9	130.4

The Zuni Canyon flow originated at two volcanic vents in the Zuni Mountains 4 miles southwest and 4 miles northwest of the head of Zuni Canyon. The lava flowed down Zuni Canyon and into the Rio San Jose valley where it underlies an area of 5 or 6 square miles, extending from the south end of the Grants Municipal Airport southeastward to 3 miles south of Grants. Basalt of the Zuni Canyon flow is black, similar to that of the McCartys basalt flow, and it overlies the Laguna basalt flow. The Zuni Canyon flow, however, appears to be more weathered than the McCartys flow and may be somewhat older. The thickness of the Zuni Canyon basalt is not known; however, differences in elevation between the surface of the Laguna flow and the surface of the Zuni Canyon flow indicate that the Zuni Canyon flow probably is not more than 40 feet thick.

The McCartys basalt flow is a very recent, narrow tongue of basalt that overlies the Laguna flow along the eastern margin of Malpais Valley; it occupies most of the floor of the Rio San Jose valley from the vicinity of Horace Springs eastward to the vicinity of McCartys, east of the area included in this study. The McCartys basalt flow originated in the same general area as the Laguna flow. Like the Laguna and Bluewater flows, it is composed of vesicular basalt. The McCartys basalt flow, however, is black, whereas the older basalt flows are grayish black and have a reddish cast on exposed and oxidized surfaces. The lack of weathering on exposed surfaces of the McCartys basalt flow indicates that it is of Recent age.

The alluvium and basalt of Quaternary age form a common aquifer in the Grants-Bluewater and Malpais Valleys. The basal part of the alluvium is the most permeable, and most of the water-table wells have been drilled through the basalt and into the underlying sand and gravel in order to obtain adequate supplies of water. The basalt appears to be sufficiently fractured to act as an aquifer, but interconnection between pore spaces and cavities in the basalt is relatively poor. The basalt penetrated by several wells was dry throughout, and only the underlying alluvium yielded water in adequate amounts. The alluvium and basalt yield adequate supplies of water for stock and domestic use at many places in the valley areas and for irrigation, municipal, or industrial use in the most favorable places. (See table 4.)

GROUND WATER

Ground water is the most dependable source of water supply in the Grants-Bluewater area. The water is obtained principally from limestone and sandstone of Permian age and from alluvial sand and gravel of Quaternary age. Water in smaller quantities is obtained from sandy siltstone and sandstone of Triassic and Jurassic ages and basaltic lava of Quaternary age.

Basic Concepts

Ground water is affected by well-defined physical principles, which were described vividly by Meinzer (1923a, p. 2-102). The following summary is adapted in part from his work.

Most of the rocks that form the earth's crust contain interconnected openings, such as joints, solution channels, and spaces between sedimentary particles. These openings in the rocks make possible the storage and transmission of water. The volume of hydrologically accessible interstices control the storage of water, and the size and degree of interconnection of the openings control its transmission. Therefore, an understanding of the distribution and physical character of the rocks in an area is essential to an appraisal of its ground-water resources.

The most common openings in limestone are pore spaces, joints, openings along bedding planes, and solution cavities. Alluvium contains pore spaces between particles of silt, sand, and gravel. The grains in sandstone commonly are cemented with calcium carbonate, iron oxide, silica, or other chemical precipitates. Unless the sandstone is completely cemented, however, interconnected pore spaces between the granules allow some storage and movement of water. Fractures also are common in sandstone. Openings in soft shale and mudstone generally are infinitesimal, but well-indurated shale and mudstone may have open joints. Basalt flows commonly contain many vesicles formed by gas bubbles in the molten material before solidification, but the vesicles may be separated by impervious material, which impedes or prevents movement of water through the rock. Basalt in many places contains side joints, scoriaceous zones, and even tunnels, which allow free passage of water.

The zone in which the rocks are saturated with water under hydrostatic pressure is termed the "zone of saturation." A saturated section of rock that will yield water to wells or springs is known as an "aquifer." The upper surface of the zone of saturation, if not confined, is known as the "water table." It is the surface at which the pressure is atmospheric. The pressure below the water table is greater than atmospheric; that is, hydrostatic pressure contributes to the total pressure. The pressure is less than atmospheric above the water table, and water is held up by capillary force, forming the "capillary fringe." The interstices in the lower part of the capillary fringe may be full of water but do not constitute a part of the zone of saturation, as defined. If the water in an aquifer is under sufficient pressure to rise in wells above the zone of saturation, it is termed "artesian." Artesian pressure may develop in the aquifer in areas where the aquifer is overlain by an impermeable bed or by a bed having low permeability. The "piezometric surface" of an aquifer is an imaginary surface that everywhere coincides with the static level of the water in the aquifer and, therefore, is the surface to which water in an aquifer will rise under its full pressure head. Artesian wells flow in areas where the piezometric surface is above the land surface. The pores of rocks and soil above the zone of saturation are filled with air, or with air and water. Water in rocks above the water table tends to move downward toward the zone of saturation, but a part of it may be used by plants or evaporated, and thus prevented from reaching the water table.

Various terms, such as "porosity" and "permeability," that pertain to hydrology have been applied to physical properties of rocks. The porosity of a rock is expressed as the percentage of the total volume of the rock that consists of pore spaces or interstices. The "specific yield" of a rock is the percentage of its total volume that is occupied by gravity ground water. The rate at which a rock will transmit water under hydraulic pressure is termed "permeability." The degree of permeability is measured by the rate at which a rock will transmit water through a unit cross section under a stated pressure-head difference per unit of distance. The coefficient of permeability is defined as the number of gallons of water a day that will pass through a 1-square-foot cross-sectional area at right angles to the direction of flow, under a unit hydraulic gradient at 60°F. The field coefficient of permeability is based on the same units, except that no temperature adjustment is necessary. The coefficient of transmissibility is defined as the number of gallons of water a day that will pass through a vertical strip of the aquifer 1 foot wide and extending the height of the aquifer, under a unit hydraulic gradient, at the prevailing temperature of the water in the aquifer; it is the field permeability multiplied by the thickness of the aquifer, in feet.

The "coefficient of storage" of an aquifer is defined as the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. The coefficient of storage of a nonartesian, or water-table, aquifer is nearly the same as the "specific yield," which is defined as the ratio of the volume of water that will drain by gravity from a saturated rock to the total volume of the rock, generally expressed as a percentage. The coefficient of storage of a water-table aquifer usually is between 0.05 and 0.30.

The coefficient of storage of an artesian aquifer differs from that of an unconfined, or water-table, aquifer in that the aquifer does not drain with changes in storage. The water released from or taken into storage in response to a change in the pressure head is attributed solely to the compressibility of the aquifer material and of the water. The volume of water released or stored per unit surface area of the aquifer per unit head change, therefore, is very small as compared with that in a water-table aquifer; it usually is between 0.00001 and 0.001 but may vary considerably beyond these limits.

The Water Table

The water table in the area is indicated by the static water levels in wells that tap the alluvium and basalt (pl. 2). Water levels in some of the wells that tap the San Andres and Glorieta formations along the southwestern margin of Grants-Bluewater Valley also may indicate the position of the water table. The water table generally is not level or uniform but is an irregular, warped, sloping surface which conforms in a general way to the configuration of the land surface. Irregularities in the direction or amount of slope of the water table are caused by variations in the amount of recharge to the aquifer, by differences in the thickness or permeability of the aquifer, and by variations in discharge from various parts of the aquifer. The water table in areas where the amount of recharge is large may be higher than in surrounding areas, forming low mounds or ridges. Depressions in the water table may indicate areas of reduced recharge or places where ground water is discharged, such as along streams entrenched below the water table or in areas of pumped wells. Depressions in the water table may be found also in places where water is transpired.

The depth to the water table is a little more than 150 feet near the mouth of Bluewater Creek, but it is shallower to the southeast and is 80 to 100 feet in much of the area between Bluewater and Toltec Siding. The depth to the water table generally is 10 to 25 feet in the vicinity of Grants and San Rafael and is only a few feet near Horace Springs. The depth to water in Malpais Valley generally ranges from 25 feet east of San Rafael to 100 feet 7 miles south of San Rafael and continues to increase southward. The depth to water near the southern boundary of the area, at the western margin of Malpais Valley, is 327 feet in well 9.10.33.110 and is 225 feet at the eastern margin of the valley in well 9.9.29.224. (See table 4.)

The water table seldom is stationary; it fluctuates in response to additions to or withdrawals from the ground-water reservoir. The magnitude of change in the ground-water level is an index to the variation in the amount of water stored in the aquifer. To determine the nature of water-table fluctuations and to record the changes in water level in response to withdrawal of ground water for irrigation, a continuing program of water-level measurements was begun in the Grants-Bluewater area in February 1946. Water levels have been measured in about 35 wells in February of each year. A recording gage has been maintained since November 1946 on well 12.11.9.221, 2.5 miles north-northwest of Bluewater.

Water levels in a few wells have been measured bimonthly or quarterly as well as annually. The water levels measured in February of each year are indices of the net changes in ground-water storage from year to year. Seasonal fluctuations of water level due to pumping and recharge are reflected in the bimonthly or quarterly measurements. Annual water-level measurements taken from 1946 through 1950 and recorder-well data taken from 1946 through 1955 were published in water-supply papers of the Geological Survey. Annual measurements taken since 1950 and recorder-well data taken since 1955 are published in the technical reports of the State Engineer.

Ground-Water Recharge, Movement, and Discharge

Recharge

The ground-water reservoirs in the Grants-Bluewater area are recharged principally from precipitation and runoff on outcrops of the San Andres limestone and Glorieta sandstone on the northeastern flank of the Zuni Mountains; from precipitation on the alluvium and the basaltic lava flows that underlie parts of the area; from seepage of water from Bluewater Lake, Bluewater Creek, and the irrigation canal system; and from seepage of irrigation water applied to the land.

A small portion of the direct precipitation is absorbed by the rocks, moves downward beyond the reach of plant roots, and eventually reaches the water table. Virtually all the precipitation eventually contributes to the runoff of streams or is returned to the atmosphere by evaporation and transpiration. The amount of recharge from precipitation to the geologic formations in the Grants-Bluewater area is not known, but it probably is much less than 1 inch per year.

A considerable amount of recharge to all the aquifers probably is derived from precipitation on outcrops along the flank of the Zuni Mountains southwest of the Grants-Bluewater Valley and from intermittent runoff from that area. The shape of the water table in the vicinity of Ojo del Gallo, near San Rafael (pl.2), indicates that a considerable amount of the runoff recharges the alluvium and basalt.

Recharge to the ground-water reservoir from seepage was very great during those years in which water was released from Bluewater Reservoir for irrigation. Water losses from Bluewater Creek and the irrigation canals near the fault at the mouth of Bluewater Canyon were reported by personnel of the Bluewater Irrigation District to be between 20 and 40 percent of the total amount of water passing the gaging station just above the mouth of Bluewater Canyon. These seepage losses, especially those in secs. 5, 8, and 9, T. 12 N., R. 11 W., were a major source of recharge to the San Andres and Glorieta formations. The water that seeped underground apparently passed almost directly into solution channels and passages in the San Andres limestone. Recorder well 12.11.9.221, 2 miles east of the mouth of Bluewater Canyon, had a large and positive response within a few days to the release of water into the irrigation-canal system. The general water-level trends in the well are shown in figure 8.

Recharge to the ground-water reservoir locally through the alluvium and basalt is demonstrated by the hydrograph (fig. 9) of well 12.11.14.213. The well was drilled in 1949, and the water level at that time was 99 feet below land surface. The water level remained relatively stable, from 98 to 100 feet, from 1949 until 1956. A disposal pond for effluent from a uranium mill was constructed in 1955 about a mile east-southeast of the well, and the pond attained a size of 30 to 40 acres. The water level in the well began to rise steadily in August 1956, and it was 89.5 feet below the land surface in May 1958, about 10 feet higher than in June 1956. Changes in chemical content of water from other wells in the vicinity indicate that water from the disposal pond moved downward to the water table and into the San Andres and Glorieta formations as well as into the alluvium and basalt. The San Andres limestone locally is in contact with the alluvium and basalt, so that recharge to either affects directly the recharge to the other. The discharge of artesian water from the San Andres limestone in some places may be a major source of recharge to the alluvium and basalt.

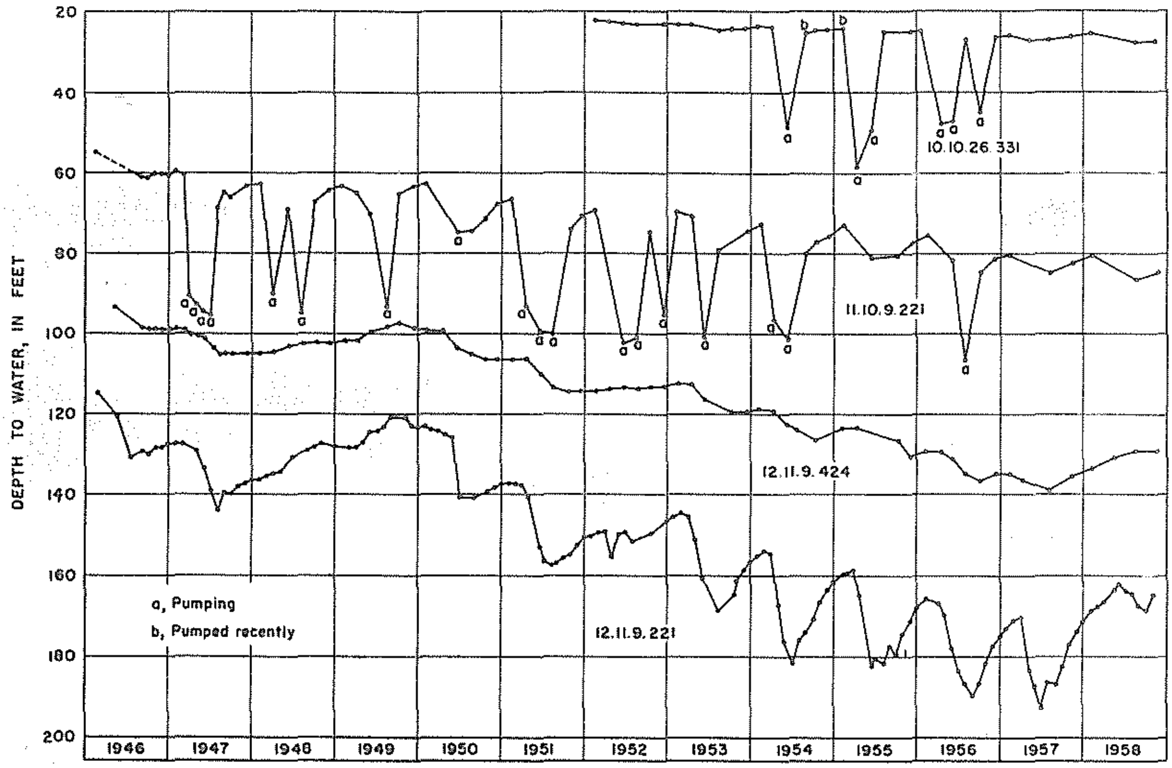


FIGURE 8. -- Graphs showing fluctuations of water levels in four wells in the Grants-Bluewater area, Valencia County, N. Mex. (10.10.26.331, 11.10.9.221, 12.11.9.424, 12.11.9.221).

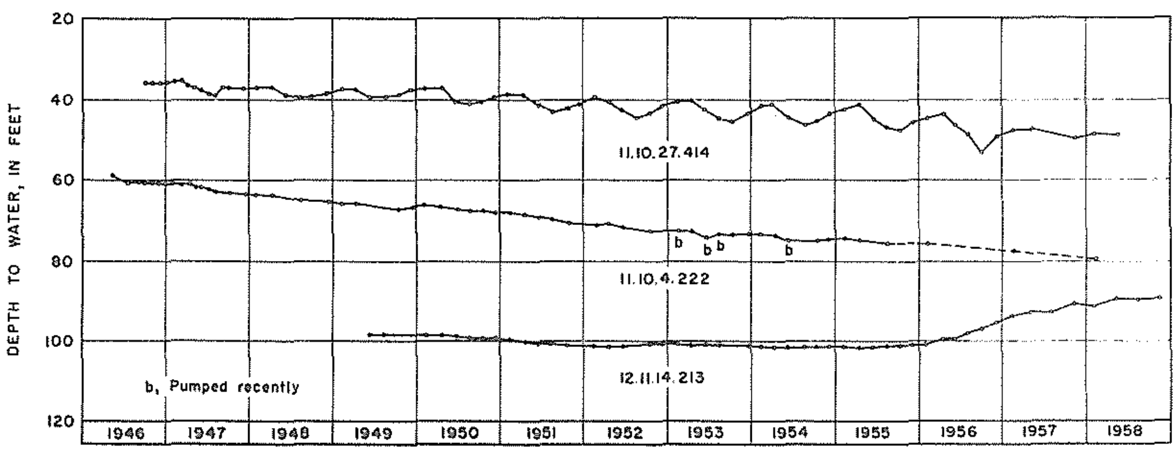


FIGURE 9. -- Graphs showing fluctuations of water levels in three wells in the Grants-Bluewater area, Valencia County, N. Mex. (11.10.27.414, 11.10.4.222, 12.11.14.213)

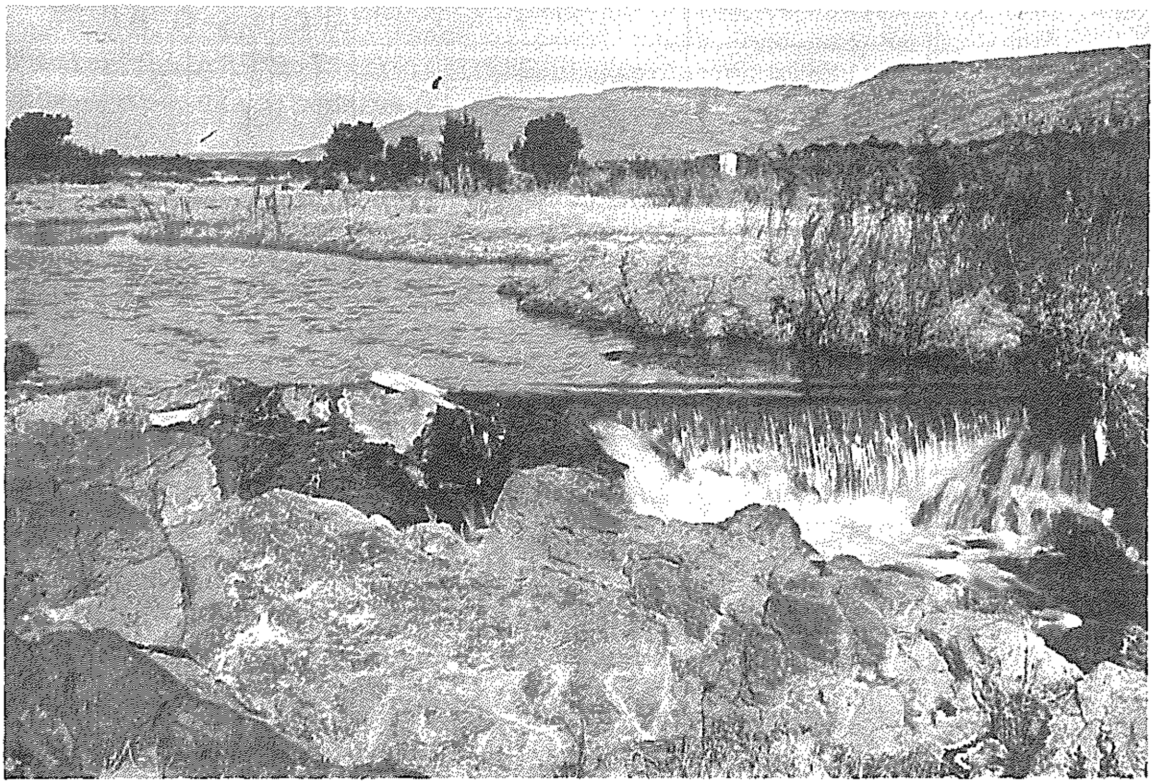


FIGURE 10. -- Rio San Jose at U. S. Geological Survey gaging station about half a mile below Horace Springs. Most of the base flow is from Horace Springs (4.9 cfs when photographed December 9, 1948). View is northward toward Horace Mesa from the SE$\frac{1}{4}$ sec. 23, T. 10 N., R. 9 W., Valencia County, N. Mex.

Movement

Ground water moves slowly from areas of recharge to areas of discharge. The rate of movement is controlled largely by the physical character of the containing rocks and the slope of the water table. The water may move through several different aquifers during its underground passage to points of discharge. Ground water moves downgradient, generally at right angles to the contours of the water table (pl. 2).

Ground water in the alluvium and basalt near the McKinley-Valencia County line moves southward in the Rio San Jose valley and southwestward in the San Mateo Creek valley. Ground water in Bluewater Creek valley moves southeastward toward the village of Bluewater. Ground-water recharge from the Mount Taylor area probably moves westward down Lobo Creek valley north of the Grants Ridges, but data were inadequate to contour that part of the area. Ground water from these sources is funneled into the Rio San Jose valley south of Toltec Siding and west of Black Mesa and moves southeastward along the Rio San Jose valley from Milan, at the foot of Black Mesa, to points of discharge near Horace Springs (fig. 10).

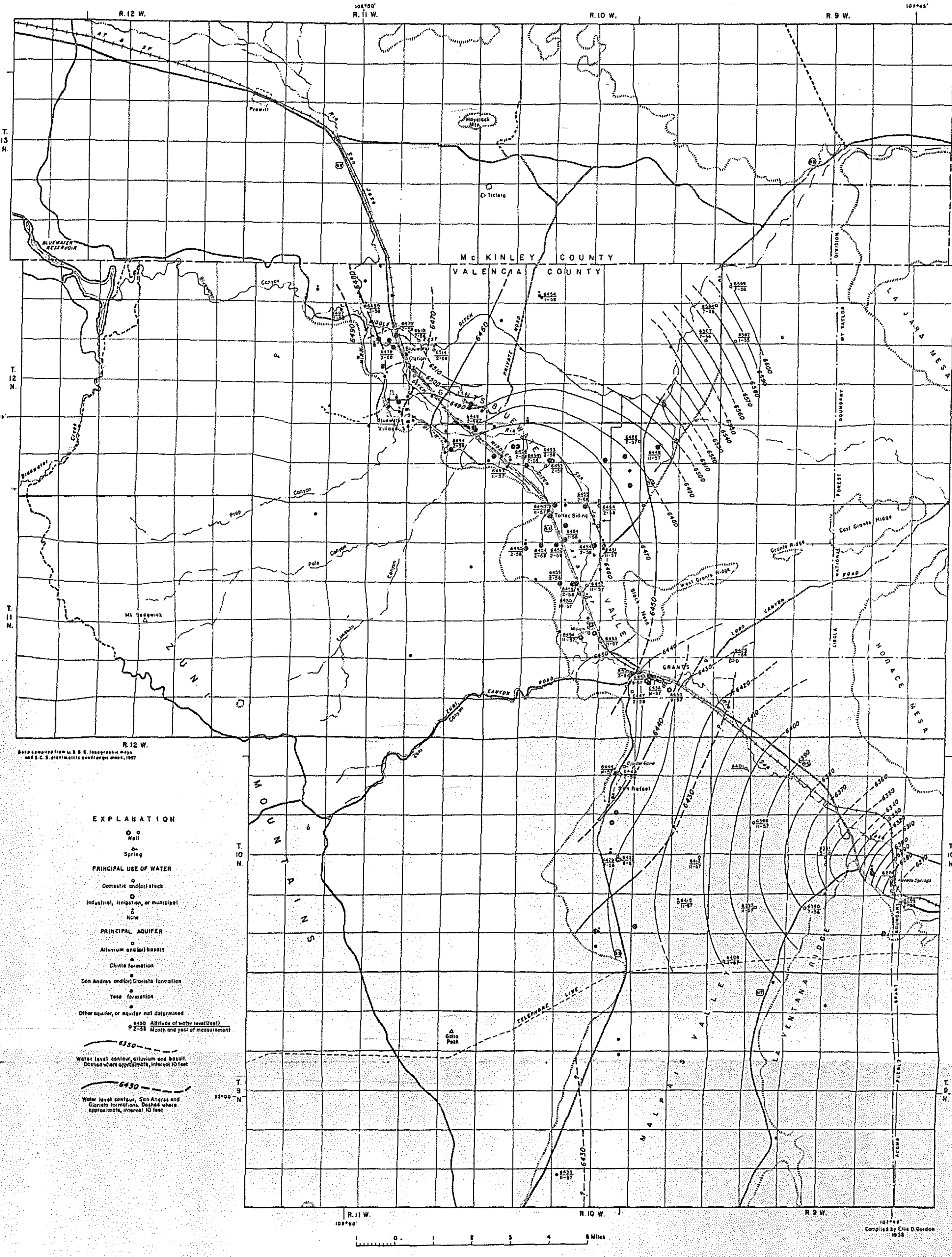


PLATE 2

LOCATIONS OF WELLS AND SETS OF WATER-LEVEL CONTOURS IN THE GRANTS-BLUEWATER AREA, VALENCIA COUNTY, N. MEX.

Ground water in Malpais Valley, in the southern part of the area, moves northeastward down the valley toward Horace Springs.

The direction of movement of artesian ground water in the San Andres and Glorieta formations is indicated by the heavy contour lines on plate 2. A major source of recharge to the artesian ground water is in the area where Bluewater Creek crosses the prominent fault zone. The water moves generally southeastward from this area toward Bluewater and Grants and toward a discharge area at Ojo del Gallo.

The piezometric surface is nearly flat between Bluewater and Grants, and the direction of ground-water movement is indistinct for several reasons. The cavernous zones and solution channels in the San Andres limestone are interconnected to a high degree. Thus, water can move easily through the strata under low pressure gradients, as indicated by the many wells in this locality that have large yields and small drawdowns. Also, the San Andres and Glorieta formations are recharged considerably from the directly overlying alluvium and basalt. A detailed inspection of water-level elevations in the area, between Bluewater and Grants, as shown in plate 2, reveals that the two sets of water-table contours are approximately coincidental, suggesting that the two aquifers are hydraulically interconnected and that water can move easily from one aquifer to the other.

Discharge

Ground water is discharged from the Grants-Bluewater area by spring flow, seepage into streams, underflow from the area through permeable strata, evapotranspiration, and pumping from wells. The rate at which water is discharged varies during the year. Spring flow and seepage into streams usually are greatest in the spring, when ground-water levels are at or near the maximum stage. Evapotranspiration is greatest during the daylight hours of the growing season.

The two principal points of ground-water discharge until recent years were Ojo del Gallo, an artesian spring near San Rafael, and Horace Springs, 8 miles southeast of Grants. (See table 5.) The discharge from Ojo del Gallo was almost entirely from the San Andres limestone, whereas the discharge from Horace Springs is from the alluvium and basalt. A part of the water discharged from Horace Springs may, however, have been transmitted to the alluvium and basalt from the San Andres limestone between Grants and San Rafael.

The discharge from Ojo del Gallo declined gradually during the late 1940's, as water levels declined in the heavily pumped irrigated area. Water has not been available from Ojo del Gallo for irrigation of farms since 1951 or for irrigation of gardens in San Rafael since 1953. During the past few years the former spring pool has been dry most of the time. The effects of pumping from the San Andres and Glorieta formations probably have reached Ojo del Gallo, and depletion of the spring flow probably is due to general lowering of the piezometric surface in the aquifer.

The flow of Horace Springs has not declined, and it is doubtful if it will decline much for many years. A decline of 5 to 12 feet in the piezometric surface was required to stop the flow from Ojo del Gallo. Horace Springs, however, are about 175 feet lower than Ojo del Gallo; a large decline of the water level, therefore, would be required to seriously affect the flow of Horace Springs, unless their discharge can be diminished by pump interception of water from the San Andres limestone that otherwise would be discharged into the alluvium and basalt.

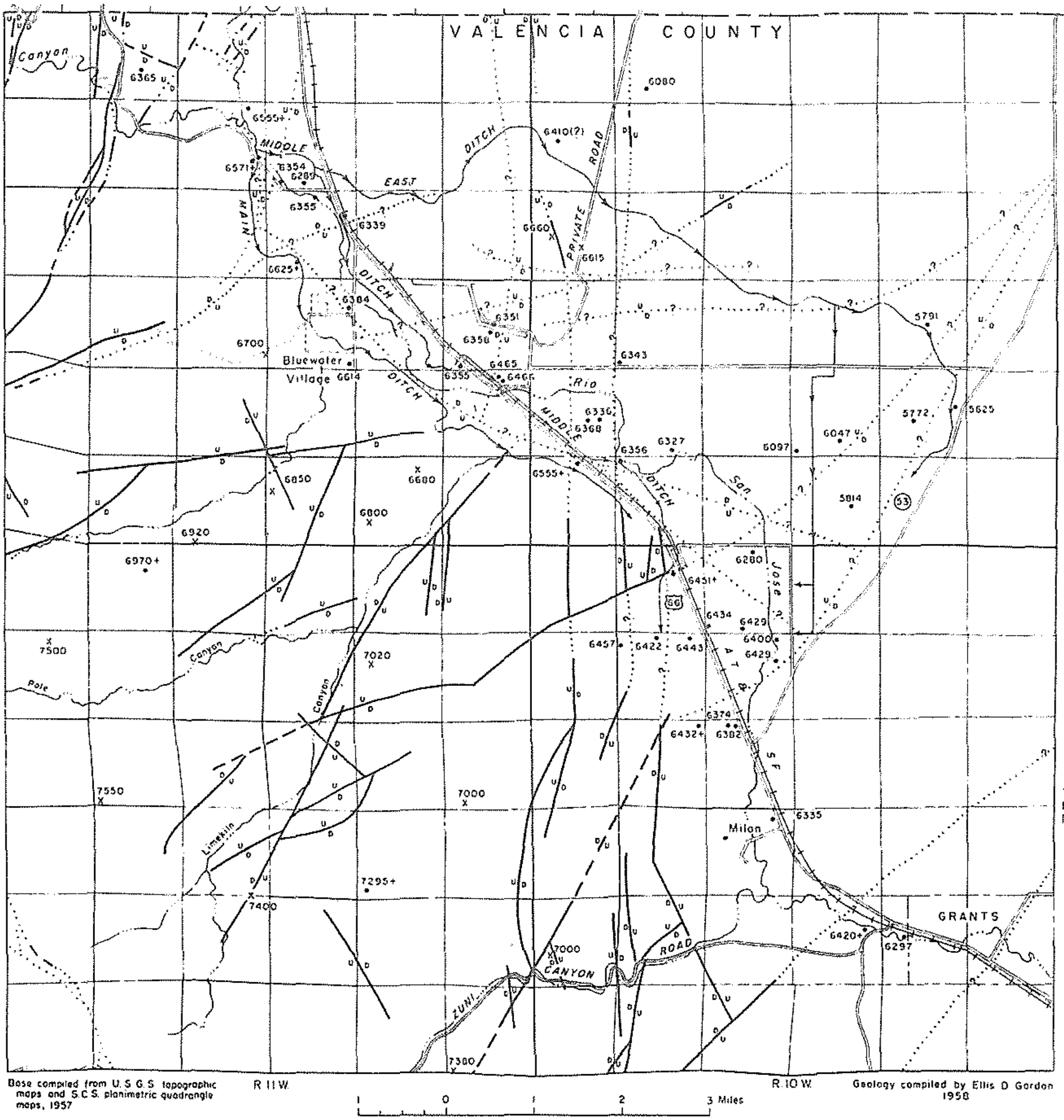
Relation of Geologic Structure to Ground Water

Successively younger beds are exposed from west to east in the Grants-Bluewater area because of the northeastward to eastward dip of the sedimentary strata. Beds exposed high in the Zuni Mountains southwest of Grants and Bluewater are buried deeply along the eastern side of the area. Rocks of Permian age -- the Yeso formation, the Glorieta sandstone, and the San Andres limestone -- are exposed widely southwest of U. S. Highway 66 (pl. 1). The San Andres limestone forms a prominent dip slope southwest of the Grants-Bluewater Valley. The altitude of the top of the San Andres limestone in a part of the Grants-Bluewater area is shown in figure 11.

The sedimentary strata southwest of U. S. Highway 66 are drained of water in many places because of their high structural and topographic position. A few springs in the area are fed from local perched-water bodies high above the principal water table. In general, however, perched-water bodies in the area have been extremely difficult to locate.

The Glorieta sandstone and the San Andres limestone dip beneath the principal water table, near the margin of the main valley, and the water-table wells in the valley along the southwest of U. S. Highway 66 tap these formations or the overlying alluvium and basalt. The Glorieta and San Andres formations in the central and northeastern parts of the valley dip beneath the confining beds of the Chinle formation, causing the water in those formations to be under artesian pressure. The line of change from water-table to artesian conditions is not well defined, because of fluctuations of water levels with the seasons and with pumping. The artesian pressure is indicated by a rise in water level above the point where water is first penetrated by the drill. Lowering of the water level by pumping tends to shift the line of transition northeastward, by lowering the water level below the confining bed; a rise in the water table tends to shift the line of transition southwestward. Most of the irrigation and industrial wells in the eastern part of the valley area obtain water under artesian pressure from the Glorieta and San Andres formations. Some of these wells, however, tap the Chinle formation or the alluvium and basalt. Because the beds of sandstone in the Chinle formation are interbedded with clay and siltstone, nearly all the wells tapping the Chinle formation are artesian. Most of the wells producing from the alluvium and basalt are water-table wells.

The occurrence and movement of water in the area is affected by numerous faults. The locationsof many of the faults are shown on plate 1



EXPLANATION

● 5625	X 6660	D / U
Altitude of top of San Andres limestone in well; + following altitude figure denotes eroded top of formation.	Approximate altitude of top of San Andres limestone at selected points on outcrop.	Fault; dashed where approximately located or doubtful; dotted where covered by alluvium or basalt (D, downthrown block; U, upthrown block).

FIGURE 11. -- Map of a part of the Grants-Bluewater area showing principal faults and the altitude of the top of the San Andres limestone at selected points in wells and on the outcrop, Valencia County, N. Mex.

and figure 11. Faults having a displacement greater than the thickness of the aquifer may impede or block the movement of water because of the faulting of water-bearing strata against relatively impervious strata. On the other hand, some fault zones may become avenues for movement of water because of fissures in the rocks adjacent to the faults.

The large northward-trending fault in secs. 5, 8, and 9, T. 12 N., R. 11 W. (pl. 1 and fig. 6), displaced the San Andres and Glorieta formations upward on the west side of the fault, where they are drained of water. The fractured zone along the fault, however, allows large quantities of water to seep into the San Andres and Glorieta formations immediately east of the fault scarp. Northward- and northeastward-trending faults near Bluewater and the Anaconda Co. uranium mill may affect the movement of water considerably. The water table north and northwest of Bluewater is characterized by large seasonal fluctuations and by large declines in response to large withdrawals of water. The water-bearing formations from the Anaconda Co. uranium mill southeastward toward Grants are characterized by high permeability and by uniformly gradual seasonal fluctuations of water level. The northeastward-trending fault zone through Grants and San Rafael has a displacement of many hundreds of feet and has greatly impeded the movement of water through the area. Ojo del Gallo is on this fault. The Chinle formation has been downfaulted against the San Andres and Glorieta formations, blocking water movement and forcing the water to rise to the surface along the fault zone.

Ground-Water Development and Use

Ground water in the Grants-Bluewater area was used principally for stock and domestic supplies until recent years, although discharges of some of the larger springs in the area have been used many years for irrigation. Large quantities of ground water have been pumped for irrigation use since 1944, and significant quantities of ground water have been utilized in industry since 1951. If the present trend continues, the water eventually will be used predominantly in industry. The locations of wells in the Grants-Bluewater area, for which records were obtained, are shown in plate 2. Records of wells are shown in table 4.

Domestic and Stock Use

Most of the domestic and stock wells were drilled after 1900. Nearly all were drilled by the cable-tool method and have steel casing; a few were dug. Not all the stock and domestic wells were inventoried, although nearly all in sparsely settled areas were. Representative wells were selected for inventory in areas where wells were numerous.

Springs provide water for domestic use in a few places, and many springs in the Zuni Mountains and on the mesas in the vicinity of Mount Taylor provide water for stock supplies; a few provide seasonal domestic supplies.

Relatively small quantities of water are adequate for stock and domestic use, as compared with quantities required for municipal, industrial, or irrigation use; as a result, stock and domestic wells tap most of the geologic formations in the area. Most, however, tap the San Andres limestone or the alluvium and basalt aquifer.

The diameter of the casing in most of the wells is 5 or 6 inches, although 4-inch-diameter casing was used in many. A few wells equipped with casing 8 or more inches in diameter are used for stock or domestic supplies. Some of the larger-diameter wells were drilled as test wells for irrigation but failed to yield adequate quantities of water.

If a stock or domestic well yields 5 gpm and is pumped 5 hours per day throughout the year, the well would yield about 550,000 gallons, or 1.7 acre-feet of water per year. Few stock and domestic wells are pumped to that extent; about 1 acre-foot of water per well per year is a more realistic estimate.

Irrigation Use

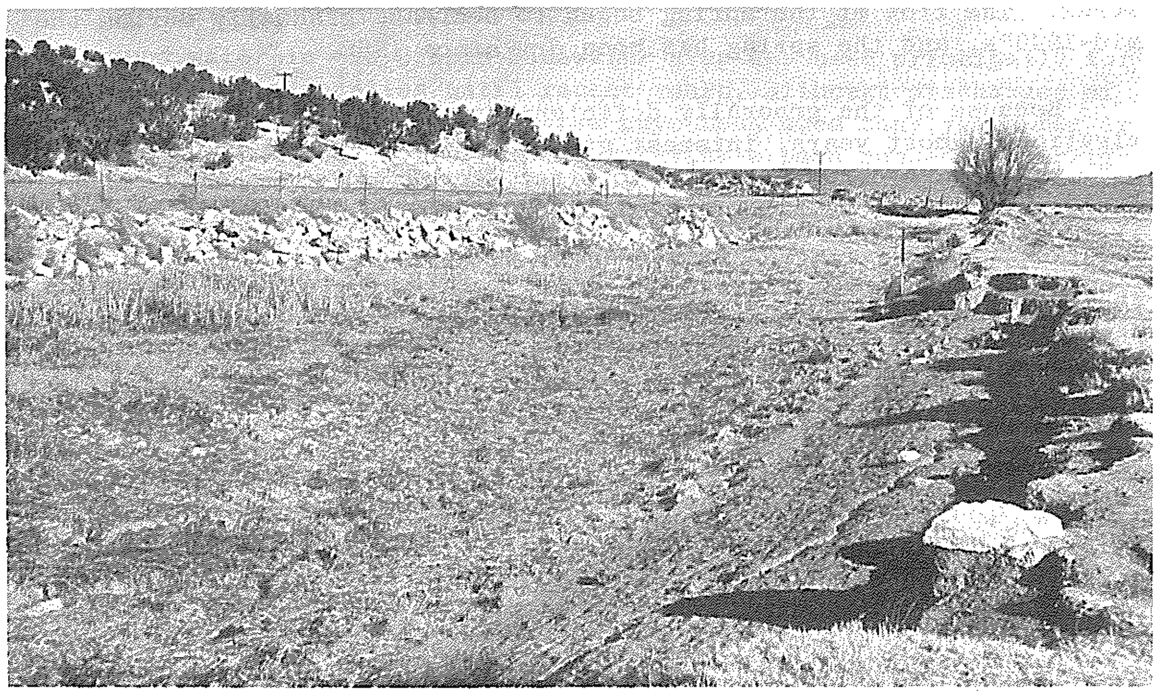
The discharge of an artesian spring, Ojo del Gallo, at San Rafael (fig. 12) had been used for many years to irrigate 1,200 acres of land along the west side of Malpais Valley. The flow of this spring was estimated by Morgan (1938) to be 7 cfs (cubic feet per second), or about 3,100 gpm. The discharge of the spring during the winter was allowed to flow eastward into an adjacent swampland, or vega, having an area of 1,100 acres. The flow of the spring began to decrease gradually during the mid-1940's, and the spring has been dry since 1953.

Because of the generally deficient supply of surface water for irrigation in most years, interest gradually increased in the possibility of pumping water from wells. The first successful irrigation well in the Grants-Bluewater area (well 12.10.29.434) was drilled in August 1944, and the number of irrigation wells increased to 16 by the end of 1946. A total of 28 irrigation wells had been drilled in the area by the end of 1954, and 23 of these were in use during the 1954 irrigation season. In addition to the irrigation wells, 3 industrial and 4 municipal wells had been drilled by the end of 1954.

Additional development of ground water for irrigation has been negligible since 1954. Two additional wells intended for irrigation use were drilled in 1955, but one of these has been converted to an industrial-supply well; several of the older irrigation wells also have been converted to industrial use. The amount of ground water pumped for irrigation, the irrigated acreage, the number of wells used, and the number of water levels measured annually in the area during the period 1945-57 are shown in table 7.

Nearly all the irrigation wells tap the San Andres limestone. A few wells tap both the alluvium and the San Andres limestone, and three small irrigation wells tap only the alluvium. Three irrigation wells tap the Chinle formation; however, several test wells for irrigation that tapped the Chinle formation were abandoned because the quality of water was too poor for irrigation.

A. Ojo del Gallo, a quarter of a mile north of San Rafael, Valencia County, N. Mex., in the SE$\frac{1}{4}$ sec. 3, T. 10 N., R. 10 W., on December 9, 1948. The flow of water from the spring was estimated to be about 5 cubic feet per second.



B. Ojo del Gallo on December 19, 1956. The water table was then below the floor of the former spring pool.

FIGURE 12

The average annual yield of irrigation wells in the area during the period 1945-57 was 508 acre-feet per well.

Industrial Use

Ground water has been used in industry extensively only in the past decade. Eight large-capacity wells had been drilled for or converted to industrial use by the spring of 1958. All industrial wells tap the San Andres limestone. The wells range in depth from 135 to 971 feet. Yields reportedly range from 200 to 2,400 gpm. Many of the wells are capable of much larger yields, and some could yield more than 3,000 gpm, but their yields are restricted by pump capacity or by the needs of the industry.

The first industrial well (11.10.26.133) probably was completed in 1944 at a depth of 135 feet, but definite records are not available. The present owner reported that the well may have been deepened, perhaps to as much as 300 feet, before he bought the site. The depth could not be measured because of an obstruction in the casing just below the end of the pump column. The well probably was drilled into the San Andres limestone. It provides water to the Grants Lumber and Box Co. plant in Grants and to several company-owned houses adjacent to the plant.

The Anaconda Co. uranium mill was the first industrial plant in the area to develop and utilize large quantities of ground water. The first Anaconda Co. well (12.11.24.411) was completed in 1951 at a depth of 360 feet; it discharged about 850 gpm with a small drawdown. A second well (12.11.24.233) was completed in 1955 at a depth of 386 feet and was tested at 2,100 gpm. Well 12.11.25.213, depth 236 feet, was converted from irrigation to industrial use in 1956. The well is pumped at about 2,400 gpm.

Well 11.10.27.241, a supply well for the ice plant at Grants, was drilled to a depth of 158 feet in 1952. The well discharged about 1,600 gpm. The Dow Chemical Co. completed well 11.10.4.333 in 1947 at a depth of 198 feet. Well 12.10.26.322a, depth 870 feet, drilled in 1955 as an irrigation test well, was completed as an industrial well early in 1958, and well 12.10.26.242 was drilled to a depth of 980 feet. The two wells are used to supply water for the twin uranium mills built by Homestake-Sapin and Homestake-New Mexico Partners. These two wells are at a greater distance from the outcrop than most of the wells that tap the San Andres limestone, and the water contains a larger amount of dissolved solids than water from other industrial wells nearer the recharge area.

Municipal and Community Use

The water systems of four municipalities (Grants, Bluewater, Milan, and San Rafael) and one community (the Anaconda Co. housing area) are supplied by wells. In addition, many motels and trailer courts have wells.

Grants (population about 10,200) was supplied by three closely spaced drilled wells adjacent to the Rio San Jose, in the southern part of the city until 1958. City wells 1, 2, and 3, which range in depth from 95 to 111 feet, tap the alluvium and basalt. The depth to water in these three wells was 11 feet in October 1946, but the water level had declined to 29 feet by February 1957. Initial yields of the wells were about 80 gpm for well 1 and about 500 gpm each for wells 2 and 3. Declining yields from these wells and a rapid increase in water requirements led to a decision in 1957 to drill a deeper well. City well 4 was completed in June 1958 at a total depth of 245 feet in the San Andres and Glorieta formations. The depth to water in the well was 22 feet. A pumping test of the well in June 1958 indicated a yield of 2,100 gpm, at a drawdown of 12 feet. The use of well 4 for municipal supply has permitted abandonment of the shallow wells. Water from the well is pumped directly into the distribution system and into a large storage tank on the side of Black Mesa near the northern city limits.

Bluewater is supplied by well 12.11.22.234. The well is 260 feet deep and taps the San Andres limestone. The depth to water was 91 feet in December 1946. The well is equipped with a submersible pump, and the yield is adequate to serve the needs of the village. Water is pumped directly into the distribution system and into a storage tank on a hillside just southwest of the village.

Well 11.10.21.221, a former irrigation well, was converted to a municipal-supply well for the village of Milan in 1956. It is 150 feet deep and originally was capable of yielding more than 1,100 gpm. At the time it was converted to a municipal well, it was equipped with a pump designed to yield 400 gpm. The well taps sand and gravel in the valley fill. Well 11.10.21.144, which formerly supplied water for a vegetable-packing shed, was converted to municipal use in 1957. The well is 126 feet deep and also taps sand and gravel in the valley fill. It is equipped with a 200-gpm pump. Both wells pump water directly into the distribution system and into a large elevated tank adjacent to U. S. Highway 66, within the village limits.

The village of San Rafael for many years was dependent on a large spring (Ojo del Gallo) and on privately owned dug and drilled wells for domestic water supplies. The San Rafael village supply well was drilled to a depth of 148 feet in 1952. The well taps the San Andres limestone. The depth to water in the well was reported to be 18 feet in May 1952 and was 24 feet in February 1958. The well is equipped with an electric turbine pump having a 2-inch discharge pipe; the yield is adequate to serve the needs of the village. Water is pumped directly into the distribution system and into a storage tank on the hillside west of the village.

The housing area at the Anaconda Co. uranium mill, 2 miles east of Bluewater, is supplied with water from the mill wells. Most of the water for the housing area is pumped from well 12.11.24.411 which was drilled in 1951 as the original supply well for the mill. The well is 360 feet deep and taps the San Andres limestone. The depth to water in the well was 149 feet in February 1953 and 161 feet in February 1956. The well discharged 600 gpm during a pumping test in July 1956. The water is pumped into a large elevated tank at the mill site.

Fluctuations of Water Levels

Water levels from the mouth of Bluewater Canyon to the vicinity of Bluewater decline rapidly in response to pumping of water for irrigation and rise rapidly when surface water is released from Bluewater Reservoir into Bluewater Creek and into the distribution canals of the Bluewater-Toltec Irrigation District. The irrigated area extending southeastward from Bluewater to south of Grants, however, is characterized by smaller water-level fluctuations in reponse to pumping, much smaller seasonal fluctuations in ground-water levels, and slower responses to recharge and discharge -- even though most ground water is pumped from this area.

Seasonal Fluctuations of Water Levels

Water levels in the irrigated area usually are highest in March or April, before the beginning of the pumping season. Water levels usually decline steadily during the pumping season, rising only slightly during interruptions in pumping, and are lowest generally from July to October, at the end of the pumping season. Water levels begin to rise again with cessation of pumping and continue to rise throughout the winter and early spring.

Long-Term Fluctuations of Water Levels

North of Bluewater, water levels have declined 40 to 45 feet since 1946, the first year of record (fig. 8, well 12.11.9.221), whereas from Bluewater southeast to near Grants the levels have declined only 18 to 20 feet. The large decline north of Bluewater may be due, in part at least, to abnormally high water levels at the beginning of the period of record. The aquifer undoubtedly was recharged greatly by irrigation-canal seepage in 1941, 1942, and 1943, when flow past the gage in Bluewater Canyon during the growing season was 26,260, 16,720, and 16,880 acre-feet, respectively. In 1944, the flow past the gage near the mouth of the canyon was 8,020 acre-feet for the entire year. Since 1944, the flow past the gage during the growing season has averaged only 2,885 acre-feet per year.

Relation of Water Levels in Upper Part of Area to Flow of Bluewater Creek

A part of the following section was prepared by C. S. Conover, of the Geological Survey, in 1950; it has been modified and expanded by the writer.

Fluctuations of water levels in wells in the upper part of the Grants-Bluewater irrigated area are related closely to the flow of Bluewater

Creek. Records of water levels in recorder well 12.11.9.221 for 1948 and 1949 and records of the daily flow at the gage near the mouth of Bluewater Creek for the same period provide the basis for this section. These measurements were published in annual reports of the Geological Survey (1948-49). A graph of fluctuations of the water level in well 12.11.9.221 is shown in figure 8.

In 1948, ground water was pumped for irrigation from wells in the vicinity of recorder well 12.11.9.221 from April 10 to April 25, when water from Bluewater Reservoir became available. The water level in the recorder well declined slightly more than 2 feet during the pumping. The nearest pumped well, 12.11.10.431, is 1.1 miles southeast of the recorder well. The relatively large drawdown in the recorder well at such a great distance from the nearest pumped well in such a short time suggests that the aquifer is highly permeable but that the coefficient of storage is low. Water levels in other observation wells in the vicinity, both pumped and unused, fluctuated widely in reponse to the pumping of comparatively small quantities of water or to the seepage of small quantities of water to the aquifer from the irrigation canal. These large fluctuations in water level are such as would prevail in an aquifer whose porosity results largely from fractures, rather than from openings between the particles constituting the aquifer.

The water level in the recorder well rose 1.7 feet from January to March 1948. The total flow past the Bluewater Canyon gaging station, all of which disappeared underground after leaving the mouth of Bluewater Canyon, was 207 acre-feet during this time. Thus, the rise in water level in the recorder well was 1 foot for each 122 acre-feet of recharge to the aquifer. Data provided by the Bluewater-Toltec Irrigation District indicate that 900 acre-feet of water disappeared between the Bluewater Reservoir gaging station and the canal division point in sec. 9, T. 12 N., R. 11 W., from April 25 to October 19, when water was released from the reservoir. The total seepage loss during the period was 900 acre-feet plus the average gain in flow in Bluewater Creek through the canyon of at least 2 cfs (about 700 acre-feet during the period involved), about 1,600 acre-feet in all. The water level in the recorder well during this time rose 9.5 feet, a rise of 1 foot for each 168 acre-feet of recharge. The total recharge to the aquifer was about 1,800 acre-feet from January through October 1948. Ground-water pumpage in the vicinity was estimated to be 230 acre-feet, a net recharge to the aquifer of 1,570 acre-feet. The net rise in water level in the recorder well during the period was 9 feet, a 1-foot rise for each 175 acre-feet of recharge to the aquifer.

The seepage loss between the reservoir and the canal division point in section 9 was reported to be 748 acre-feet in 1949. Ground-water pumpage in the vicinity was 154 acre-feet. If we again assume a gain of 700 acre-feet in base streamflow, the net gain in ground-water storage in the aquifer was about 1,300 acre-feet. The water level in the recorder well in 1949 rose 7 feet, or 1 foot for each 185 acre-feet of recharge to the aquifer.

The preceding conclusions are only rough approximations. They are based on the assumptions that natural outflow from the vicinity was constant and that recharge to the aquifer, other than seepage from Bluewater Creek and the irrigation canal, was insignificant; these assumptions may not be correct.

Assuming, however, that the preceding conclusions are approximately correct, they may be used to approximate the amount of ground water that has been removed from storage in the aquifer in the upper part of the Grants-Bluewater area during 1946-57. The water level in the recorder well declined from 115.7 feet to 172.3 feet, a net decline of 56.6 feet during 1946-57. If an average of 200 acre-feet of water is removed from storage for each foot of decline in water level in the recorder well, including recharge to the aquifer from sources other than seepage from Bluewater Creek and the irrigation canal, approximately 11,000 acre-feet of water was removed from storage in the vicinity during the period.

AQUIFER CHARACTERISTICS

By

H. O. Reeder

The thickness and character of the material forming a water-bearing bed, or aquifer, have a direct bearing on its hydraulic characteristics. The two principal hydraulic properties of aquifers that influence the yield of water to wells and the accompanying lowering of water levels are: 1) the ease with which water can move through the aquifer, expressed quantitatively by the coefficient of transmissibility and 2) the coefficient of storage. The manner in which these two properties are related to the water supply of an area can best be illustrated by stating the effects of pumping a well.

A radial hydraulic gradient toward the well is established in the aquifer, as the well is pumped, and causes the water to flow toward the well. This gradient is established by a local decline of the water level, and the lowest point on the water table or piezometric surface around the well is at the pumped well. The shape of the surface is controlled in part by the coefficient of transmissibility. That is, for a given pumping rate, the greater the coefficient of transmissibility of an aquifer, the more gentle the gradient toward the well will be, resulting in correspondingly less drawdown in the well. The gradient toward the well increases as the pumping rate increases. The discharge from a well cannot be increased beyond the rate at which the hydraulic gradient can be established in the aquifer; thus, the yield that a well can maintain is restricted. The amount of restriction varies, depending on the aquifer characteristics.

The discharge of a well in the initial period of pumping is released from storage in the aquifer close to the well. As pumping continues, a greater percentage of water is released from storage at greater distances from the pumped well. The increase in volume of water released from storage at greater distances is accompanied by a decrease in the rate of decline of water level at the pumped well. The decline in water level will continue, at a decreasing rate, unless the discharge rate is changed or unless the area of influence caused by pumping reaches impervious boundaries, other areas of discharge, or areas of recharge. The greater the coefficient of storage, the less water levels need to be lowered to supply a unit volume of water.

The volumetric differences between the prepumping or static water level and the surface resulting from pumping is shown by the cone of depression. The shape and position of the cone of depression are controlled mainly by the coefficients of storage and transmissibility, the pumping rate, and the time since pumping began. The water-level decline is greatest at the pumped well and diminishes outward from the well. The effect of pumping from a well commonly is noticeable in nearby wells tapping the same aquifer, but the effect in more distant wells is less obvious. Ojo del Gallo, formerly a spring near San Rafael, has ceased to flow because of pumping water from wells.

In the Grants-Bluewater area, as in many other areas in New Mexico, recharge to the aquifer or aquifers from which wells are pumping water cannot be increased by lowering the water levels. The pumpage has exceeded the natural discharge that has been intercepted; thus, most of the water pumped must come from storage in the aquifer, and water levels must continue to decline if pumpage continues to exceed the natural discharge that is intercepted. The rate of decline in water level and the period of usefulness of the aquifer as a large-scale source of water depend largely on the amount of water pumped and the spacing of wells. Concentration of wells of large yield causes water levels to decline more rapidly in a small area, and the useful life of the aquifer will be shortened substantially. Wider spacing and moderate pumping of wells allow water levels to decline uniformly over a large area, and inflow from areas of smaller ground-water withdrawals compensate partly for the water pumped from storage.

A prediction of the rate of decline of water levels in the Grants-Bluewater area, given a spacing of wells and pumping regimen, depends largely on accurate determinations of the coefficients of transmissibility and storage. The coefficient of storage is more important than the coefficient of transmissibility in evaluating long-term effects of pumping, but is more difficult to determine. Aquifer tests involving observations of the magnitude and rate of decline of water levels in response to pumping from a well at a known rate commonly yield information from which the coefficients of transmissibility and storage can be computed. The extent to which an aquifer departs from an ideal homogeneous aquifer governs the accuracy of results of aquifer tests in which standard analytical methods are used for determining the coefficients.

Aquifer Tests

The decline of water level, in feet, caused by pumping from storage in an aquifer at a point distant from its boundaries depends upon 1) the coefficient of transmissibility (T); 2) the coefficient of storage (S); 3) the time (t), in days, since pumping began; 4) the distance (r), in feet, from the pumped well to the point where the effects are noted; and 5) the discharge (Q) of the well, in gallons per minute. The following formula developed by Theis (1935) relates the drawdown (s) to the discharge from an ideal homogeneous aquifer of large areal extent:

$$s = \frac{114.6\,Q}{T} \int_{\frac{1.87\,r^2 S}{Tt}}^{\infty} \frac{e^{-u}}{u}\,du$$

in which $u = \frac{1.87r^2S}{Tt}$ and the other symbols and units are as defined above.

For an ideal aquifer, if drawdown is plotted against the logarithm of time since pumping began, the points fall on a straight line after a sufficient period of time has elapsed, and the coefficient of transmissibility can be determined from the slope of the line. If the drawdown (s_1) in feet over one log cycle is used, the coefficient of transmissibility can be determined by use of the following equation:

$$T = \frac{264Q}{s_1}$$

The coefficient of transmissibility may be determined in the pumped well by relating the residual drawdown (s_2) to the logarithm of the ratio of the time (t) since pumping began to the time (t_1) since pumping ceased, as expressed in the following equation.

$$T = \frac{264\,Q\,\log_{10} t/t_1}{s_2}$$

Several aquifer tests were made in the Grants-Bluewater area to determine the transmissibility of the water-bearing material and to determine the effects of pumping on water levels. A test at the site of well 12.-10.30.412 was made by C. S. Conover in February 1950, and two tests at the site of well 12.11.24.411 were made by W. L. Champion, R. E. Smith, and E. H. Herrick, in October 1951. The fourth test was made at the site of well 12.10.26.322a by L. T. Putnam, M. B. Compton, and P. D. Jordan of the New Mexico State Engineer Office, in October 1956.

The coefficients of transmissibility and storage were computed from the aquifer-test data by several methods. The method of analysis used in three of the tests related the recovery of the water levels in the pumped wells to the logarithm of the ratio of the time since pumping started to the time since pumping stopped, which is a modification of the nonequilibrium method developed by Theis (1935). This procedure was used because data were collected only from the pumped wells. The coefficient of storage generally cannot be computed realistically without data on water levels in wells other than the pumped well. The observation-well method (used only for the test at the site of well 12.10.30.412) included the relation of the drawdown or recovery of the water levels in observation wells to the logarithm of $\frac{t}{r^2}$ and the relation of the logarithm of drawdown or recovery of the water levels to the logarithm of $\frac{r^2}{t}$. These relations can be illustrated and analyzed graphically. Results from three tests were fairly uniform; the coefficient of transmissibility ranged from 410,000 to 460,000 gpd (gallons per day) per foot. The results of a fourth test, however, indicated a coefficient of transmissibility that was about 8 times greater. The tests are described below, and the methods of analysis and results of all the tests are summarized in table 8.

Test in the Vicinity of Well 12.10.30.412

An aquifer test was made in February 1950 at the site of well 12.-10.30.412, 3 miles east-southeast of Bluewater. The well was pumped for 25 hours on February 9-10, 1950. Water levels were measured periodically during the test in the pumped well and in two nearby wells (12.10.30.421 and 12.10.32.111). The discharge from the pumped well was 1,745 gpm. The recovery of water levels was measured for 24 hours after pumping was stopped.

Observation wells 12.10.30.421 and 12.10.32.111 are 660 feet east and about 3,000 feet southeast, respectively, of the pumped well. The depths of the wells and related data are given in table 4, and logs of the wells are given in table 6.

The relation of recovery of the water level in well 12.10.30.412 to the logarithm of the ratio of the time since pumping started to the time since pumping stopped indicated a coefficient of transmissibility of 3,400,000 gpd per foot.

The drawdowns in the two observation wells near well 12.10.30.412 also were used to evaluate the coefficient of transmissibility. The transmissibility was calculated from the relation of the drawdown to the distance of the observation well from the pumped well, plotted as drawdown or recovery against the logarithm of t/r^2. The coefficient of transmissibility by this method ranged from 2,200,000 to 3,100,000 gpd per foot. Many of the data did not plot on a straight line, indicating that the water levels were affected by another factor or factors besides pumping. A coefficient of transmissibility of 3,100,000 gpd per foot was indicated by both the drawdown and recovery data from well 12.10.30.-421, and 2,300,000 and 2,200,000 gpd per foot were indicated by the drawdown and recovery data, respectively, from well 12.10.32.111.

Data from the observation wells also were analyzed graphically by plotting the logarithm of the drawdown or recovery against the logarithm of r^2/t. This method indicated a coefficient of transmissibility ranging from 2,000,000 to 3,200,000 gpd per foot. A coefficient of transmissibility of 3,200,000 gpd per foot was indicated by both drawdown and recovery data from well 12.10.30.421, and 2,500,000 and 2,000,000 by the drawdown and recovery data from well 12.10.32.111.

Coefficients of transmissibility indicated by the logarithmic and semi-logarithmic methods agree for the same well; that is, the coefficients at well 12.10.30.421 ranged from 3,100,000 to 3,200,000 and at well 12.10.32.111 ranged from 2,000,000 to 2,500,000. Coefficients of transmissibility at well 12.10.30.421 more nearly agree with the coefficient of 3,400,000 at the pumped well.

The coefficients of storage computed from the test ranged from 0.00042 to 0.0014, within the range of artesian conditions.

Tests in the Vicinity of Well 12.11.24.411

Two aquifer tests were made in October 1951 at the site of well 12.11.24.411, 1½ miles east of Bluewater. The well was pumped for 26 hours on October 18-19, 1951. Water levels were measured periodically during the time of pumping and for 15 hours after the pump was stopped. The discharge ranged from 575 to 625 gpm and averaged 600 gpm. The well, during the second test, was pumped for 49½ hours on October 22-24, 1951. Water levels were measured periodically during the time of pumping and for 46½ hours after the pump was stopped. The discharge ranged from 726 to 813 gpm and averaged 775 gpm.

Well 12.11.24.411 was drilled to a depth of 357 feet and cased with 182 feet of 14-inch casing and 80 feet of 12-inch casing. The 12-inch casing was factory perforated and set at 248 to 328 feet in the well. The principal aquifer tapped by the well is the San Andres limestone. Other well data are given in table 4, and the log of the well is given in table 6. One of two irrigation wells (12.11.25.213 or 12.11.25.214), three-fourths of a mile to the southeast, was pumping most of the time during the tests. These irrigation wells tap the same aquifer as the test well, and their pumping probably affected the water levels in the vicinity.

Several other events during the tests also caused irregularities in the results. The pump was stopped for 2 minutes to adjust the pump setting and for 5 minutes to refuel the engine during the drawdown part of the first test.

The well was pumped less than an hour during the 65-hour recovery period between the pumping tests, but it was not pumped within 40 hours of the beginning of the second test. The pump was stopped for 1 hour and 35 minutes to change engine oil and again for about 2 minutes to add oil, during the drawdown part of the second test.

The relation of the recovery of the water level to the logarithm of the ratio of the time since pumping started to the time since pumping stopped indicated coefficients of transmissibility in the vicinity of well 12.11.24.411 of 410,000 and 430,000 gpd per foot, respectively.

Test in the Vicinity of Well 12.10.26.322a

An aquifer test was made in October 1956 by pumping well 12.10.26.-322a, which is 6 miles north of Grants and 7 miles east of Bluewater. The well was pumped for 12 hours on October 15, during which time water levels were measured periodically. Measurements were continued for 25½ hours during the recovery of water levels, after the pump was stopped. A barometer also was read periodically in order to eliminate from the calculations the effects of changes in atmospheric pressure upon the water levels in the well. The depth of the well and related data are given in table 4, and the log of the well is given in table 6.

The discharge of the well was measured with an orifice gaging assembly, and it averaged about 2,830 gpm.

The relation of the recovery of the water level to the logarithm of the ratio of the time since pumping started to the time since pumping stopped indicated a coefficient of transmissibility of 460,000 gpd per foot in the vicinity of well 12.10.26.322a.

The large differences in the coefficients of transmissibility in the test at the site of well 12.10.30.412 (February 1950) and the tests at the sites of wells 12.11.24.411 (October 1951) and 12.10.26.322a (October 1956) are plausible because the permeability is expected to differ greatly from place to place in the San Andres limestone of the area; however, part of the large differences possibly is due to the fact that well 12.10.30.412 taps the San Andres limestone and alluvium and basalt, but the other wells tap only the San Andres limestone. Results of the tests are given in table 8.

Specific Capacities of Wells

The specific capacities of irrigation wells in the Grants-Bluewater area also were used to estimate coefficients of transmissibility. The specific capacity is largely a measure of the performance of a well and is expressed as the yield of a well in gpm per foot of drawdown. The relation of the coefficient of transmissibility to the specific capacity is affected by the diameter of the well and its effective radius, the depth of well penetration into the aquifer, the efficiency of the well, the coefficient of storage of the aquifer, and the rate and duration of pumping. The coefficient of transmissibility for most artesian aquifers roughly is 2,300 to 2,600 times the specific capacity of wells having the diameters commonly constructed for irrigation or industrial use (Theis and others, July 1954). The curves prepared by Theis for relating the coefficients of transmissibility to specific capacities of wells were used for this report. Entrance losses at a well, such as those caused by poor screens or by unclean walls in the well, may cause excessive drawdown, and the ratio of the transmissibility to specific capacity under such circumstances may be more than 2,600. The specific capacities of the wells that were tested ranged between 10 and 1,100 gpm per foot of drawdown. This range in specific capacity indicates that the coefficient of transmissibility ranges from 25,000 to 2,700,000 gpd per foot.

The specific capacities of well 12.10.30.412, determined in September 1946 and February 1950, indicate coefficients of transmissibility of 2,700,000 and 1,700,000 gpd per foot, respectively, as compared with 3,400,000 determined in an aquifer test. The specific capacity of well 12.11.24.411 indicates a coefficient of transmissibility of 1,100,000 gpd per foot, as compared with 410,000 and 430,000 determined in aquifer tests. The specific capacity of well 12.10.26.322a indicates a coefficient of transmissibility of 410,000 gpd per foot, as compared with 460,000 determined in an aquifer test. The area is cut by numerous faults, so the aquifer characteristics would be expected to differ greatly in short distances.

Specific capacities in the Grants-Bluewater area ranged from 10 to 16 gpm per foot of drawdown in well 12.11.15.341 near Bluewater to 1,100 in well 12.10.30.412, 3 miles southeast of Bluewater. The specific capacity in the area within 1½ miles of Toltec Siding ranges from 63 to 82 gpm per foot in most wells. The specific capacity was 158 gpm per foot in well 12.10.26.322a, 3 miles northeast of Toltec Siding. The specific capacity is 39 gpm per foot in well 11.10.27.241, at Grants. The localities where higher specific capacities prevail coincide with the localities that are characterized by wells of large yields that tap cavernous limestone. The area in the vicinity of Toltec Siding, where the specific capacity is relatively uniform, coincides with an area that is characterized by highly permeable aquifers and seasonal fluctuations of water levels that are uniform and gradual.

The specific capacities of wells in the Grants-Bluewater area may change with time and place; however, many more data will be required to determine trends in specific areas or wells because of the complexity of the geology. The approximate specific capacities of wells in the area are given in table 9.

CHEMICAL QUALITY OF THE GROUND WATER

By

J. L. Kunkler

Interest in the chemical quality of water has grown in recent years. This interest has been stimulated by various groups who may have different or even contradictory ideas of the optimum quality of water. The housewife needs soft water, but generally the irrigation farmer needs hard water. Industries commonly need soft water, and some industries may require water having very low concentrations of silica, iron, or other constituents; however, some industries, such as the brewing industry, prefer very hard water. Sources of water that satisfy the needs of all interests are difficult to find in most parts of the country and are especially difficult in the arid Southwest, where water that is suitable for any of the common uses may not be available. Other problems, such as disposal of industrial waste and municipal sewage, have reached such proportions that governmental agencies have become active in the field. All these problems apply in the Grants-Bluewater area. Chemical analyses of water from many wells and springs in the area are listed in table 10.

Factors that Influence Quality of Water

Recharge

Sources of recharge to the ground-water reservoir in the Grants-Bluewater area are numerous, and it is difficult to evaluate the relative influence of each. Little is known about the quality of recharge water, largely because the collection of a representative group of samples of recharge water was beyond the scope of this investigation.

The principal sources of recharge probably are precipitation and runoff on the flanks of the Zuni uplift. Bluewater Creek contributes recharge, and several other streams may contribute nearly as much. The watercourses in Prop, Pole, and Limekiln Canyons probably contribute to recharge, and the ephemeral flow in Zuni Canyon in its lower reach is a source of recharge. Ephemeral flow in the watercourses traversing the Grants-Bluewater Valley also contributes to the recharge of the ground-water reservoir. Two other sources of recharge, sewage effluent and industrial waste, might be described better as contamination. Industrial waste possibly is infiltrating into the ground-water reservoir in at least one area, and sewage may be infiltrating in several areas. Some aquifers, in addition to being recharged from surface sources, are recharged by interformational leakage and by inflow from adjacent areas.

Chemical Weathering Processes

Weathering processes generally are separated into two categories, physical and chemical. Physical processes are indirectly important to this study; chemical processes affect the quality of water directly and profoundly.

The presence of some of the solute (dissolved solids) in ground water is due to the solution of atmospheric gases and other substances in the atmosphere, but by far the greater part is due to solution of the by-products of chemical weathering within the lithologic environment. The common rock-forming minerals differ widely in their resistance to chemical weathering. The rate of decomposition is a function of many variables, such as climate, crystal structure, shape and size of crystals, and bonding strength. Part of the decomposition products of minerals remain in solution. Some of these products precipitate, and others recombine to form insoluble minerals. The types of insoluble products that are formed also are a function of many variables.

All types of rocks -- metamorphic, igneous, and sedimentary -- in the Grants-Bluewater area are subject to chemical weathering. Metamorphic and igneous rocks generally weather more slowly and contribute less solute to ground water than sedimentary rocks because they are composed, on the whole, of more insoluble minerals. The metamorphic rocks and the granite, which also is possibly metamorphic, are exposed in the crest of the Zuni uplift and are buried under sedimentary rocks at lower elevations. Extrusive volcanic rocks include both mafic (rich in calcium, iron, and magnesium) and felsic (rich in sodium, potassium, aluminum, and silica) types. The mafic rocks include basaltic lava flows in the valley and remnants of flows that cap some mesas. The felsic rocks include several textural varieties, most of which have been deposited on the flanks of Mount Taylor.

The principal chemical processes that decompose igneous rocks are hydration and carbonation. The cations removed from the rocks are hydrated to bases, and the bases are converted to carbonates. The decomposition of labradorite illustrates these principles:

(1) $Na_2Ca_3Al_8Si_{12}O_{40} + 8H_2O \rightarrow 2NaOH + 3Ca(OH)_2 + H_8Al_8Si_{12}O_{40}$. The aluminosilicic acid ($H_8Al_8Si_{12}O_{40}$), being unstable, decomposes and forms insoluble by-products, but the bases react with carbon dioxide and form carbonates.

(2) $2NaOH + 3Ca(OH)_2 + 4CO_2 \rightarrow Na_2CO_3 + 3CaCO_3 + 4H_2O$. The soluble products formed by reactions (1) and (2) are dissociated into their ionic components. The carbonate radical reacts with water and carbon dioxide to form bicarbonate.

(3) $CO_3^{-2} + H_2O + CO_2 \rightarrow 2HCO_3^{-1}$.

Thus, the soluble products resulting from the chemical weathering of labradorite, a common mineral in mafic rocks, mainly are a mixture of sodium and calcium bicarbonate.

The chemical decomposition of other common silicate minerals in mafic rocks is not so easily illustrated as that of labradorite; however, the decomposition reactions are nearly the same. The differences are that other insoluble by-products may be formed and that the soluble by-products usually include magnesium bicarbonate. Because of the formation of insoluble by-products, the correlation between the chemical composition of the lithologic environment and the soluble by-products is only qualitative. Also, the preferential removal of some ions to form insoluble by-products upsets the correlation.

The sedimentary rocks are composed of both detrital (sandstone, siltstone, and shale) and nondetrital (limestone and gypsum) types, and their mineral components range in solubility from insoluble to extremely soluble. Although the direct contributions of insoluble mineral components to the salinity of ground water is insignificant, the indirect contributions of certain insoluble clay minerals may, under favorable conditions, be significant. The Chinle formation contains numerous beds of clay that have formed through the chemical weathering of volcanic ash. The minerals constituting the clay have a strong proclivity for ion-exchange reactions, and their influence upon quality of water is disproportionate to the abundance of the minerals. These reactions usually involve the exchange of cations in solution and the loosely adsorbed cations in the clay-mineral lattice. Moreover, because of the weak bonding of the adsorbed cations, the exchange often is promiscuous, and the chemical character of the salinity is altered completely. The high concentrations of sodium bicarbonate and sodium sulfate of some waters, such as many of those throughout northwestern New Mexico, can be traced to ion-exchange reactions.

Calcite and dolomite are the most abundant of the more soluble minerals in sedimentary rocks. These minerals form isomorphic series, or so-called solid solutions, with each other, and their chemical compositions are variable. Furthermore, these minerals may contain substantial amounts of impurities. For these reasons ground water from some limestone terranes may contain considerable amounts of ions other than calcium, magnesium, and bicarbonate. The solubility of the minerals calcite and dolomite is related to an equilibrium system containing carbon dioxide and water; they are only slightly soluble in pure water. Their solubilities increase in an aqueous solution containing carbon dioxide. Furthermore, the fact that the solubility of carbon dioxide increases with pressure indirectly affects the solubilities of these minerals. Their solubility also is a function of other factors, such as temperature and salinity. The effect of these factors, however, is not evaluated in this report.

Sedimentary rocks in the area also contain anhydrite (calcium sulfate) and gypsum (hydrated calcium sulfate). Although these minerals are more soluble than the carbonate minerals, they are less abundant. Notwithstanding, they provide enough solute to render some ground water impotable. Ground water saturated with calcium sulfate generally is harder, more saline, and more disagreeable to the taste than ground water saturated with calcium or magnesium carbonate minerals.

Anhydrite and gypsum probably are the most soluble minerals in the zone of saturation in the report area. Although the Chinle formation contains some highly soluble alkaline-carbonate and alkaline-sulfate minerals, they probably are confined to the zone of aeration. Ground water in the Chinle formation is far from being saturated with these minerals. The high percentage of sodium ions in ground water in the Chinle formation is due to base-exchange reactions, not to the solution of highly soluble sodium minerals.

Faults, joints, and other structural features may contribute indirectly but significantly to the quality of ground water, especially where they serve as conduits for the vertical and horizontal movement of ground water. These fractures in some places may be growing larger through the solution of minerals by moving ground water; elsewhere, they may be growing smaller because of the deposition or hydration of minerals. Some joints and faults have been sealed by selenite, a variety of gypsum. Numerous occurrences of aragonite in the fault scarps and fault-line scarps of the Chinle formation also give support to the thesis of underground deposition. If carbonate minerals are being deposited in some of the fractures, the chemical equilibria for such deposition should become increasingly favorable toward the zone of artesian pressure. Because of the increase in solubility of carbon dioxide with increase in hydraulic pressure, ground water in the zone of artesian pressure may become supersaturated with carbonate minerals, in comparison with zones of lower pressure. Carbonate minerals, therefore, are likely to be deposited in any opening that relieves pressure.

The release of hydraulic pressure is not the only explanation for the deposition of carbonate minerals in the zone of saturation. If, as the writer believes, ground water in the Chinle formation is chemically incompatible with that in the San Andres limestone, the deposition of carbonate minerals along any surface that forms the interface between the ground waters of these formations is a possibility. Some aragonite may have been deposited in this manner.

Some ground water may be supersaturated with calcium carbonate at atmospheric pressure. Such water, aside from being unsatisfactory for many industries, would precipitate calcium carbonate upon the walls of wells, well casings, and screens, and in storage tanks.

Pumping

Heavy pumping may be affecting the quality of water locally. Chemical analyses of water samples collected over a period of years indicate that heavy pumping is improving the quality of water in the southwestern part of Grants-Bluewater Valley; it may affect the quality adversely in other areas, however.

Evapotranspiration

Little is known about the effect of evapotranspiration upon the quality of ground water in this area. The mineral content of shallow ground water in some of the basalt in the lower part of the Grants-Bluewater Valley, however, probably is being concentrated by evapotranspiration, whereas the mineral content of water in aquifers that are overlain by thick or impermeable strata is relatively unaffected.

Chemical Character of Water in the Geologic Formations

Rocks older than the Yeso formation are not included in this section because their potential for yielding ground water to wells is small. Furthermore, the environments of these older rocks do not affect the quality of ground water in the major aquifers.

Yeso Formation

The Yeso formation, like the older rocks, is not a likely source of large supplies of ground water; but, unlike the older rocks, it has been explored at various places for water supplies. Ground water may move from the Yeso formation into the major aquifers and thus may affect these aquifers. Few data are available on the quality of water in the

Yeso, but it is reported to range from fair to very poor, which is in accordance with the geologic environment.

The lower member of the Yeso formation, the Meseta Blanca sandstone member, may contain water of fair quality in places, especially near the outcrop areas in the Zuni Mountains or in or near faults that are receiving water from higher formations. The upper part of the Yeso formation, the San Ysidro member, contains considerable amounts of anhydrite and gypsum and probably contains little water of good quality.

Glorieta Sandstone and San Andres Limestone

The Glorieta sandstone and the San Andres limestone are treated as a hydrologic unit in this report. The San Andres limestone is a more productive aquifer, however, and the bulk of quality-of-water data pertain to this formation. The quality of water in the underlying Glorieta sandstone generally is similar.

The San Andres limestone is an impure, somewhat dolomitized limestone that contains some quartz sand. Lithologically the Glorieta sandstone grades into the San Andres limestone, but, in general, the Glorieta contains a higher percentage of insoluble clastic material. These formations do not contain significant amounts of other soluble minerals, and much of the solute in the ground water of these formations consists of calcium, magnesium, and bicarbonate ions. Some ground water in these formations, however, also contains high concentrations of sodium and sulfate ions.

These different types of water occur within relatively short distances of each other, and the salinity varies within wide limits. Water from well 11.10.8.111, which taps the San Andres limestone near its outcrop, had a salinity of 354 ppm (parts per million) in July 1946, as compared with 2,170 ppm at the same time in the water from well 12.10.-23.233, which taps the San Andres limestone 4 miles east of its outcrop. The water-level contours (pl. 2) indicate that water in the San Andres does not move directly from well 11.10.8.111 to well 12.10.23.233, but that it does move eastward from the outcrop. Well 11.10.8.111 had a concentration of 20 ppm of sodium and potassium, as compared with 379 ppm for well 12.10.23.233. The difference in salinity was about 6 fold, but the difference in sodium and potassium concentration was about 19 fold. If these differences are compared on the basis of chemical equivalents, which is more useful, they become more significant. Water from well 11.10.8.111 contained 0.87 epm (equivalents per million, a concentration involving reactive weights) of sodium and potassium, which is 14 percent of the total equivalents per million of cations. By comparison, the water from well 12.10.23.233 contained 16.49 epm of sodium and potassium, which is 45 percent of the total equivalents per million of cations. This comparison indicates a difference in sodium concentrations that is disproportionate to the difference in other cation concentrations.

The analyses of water from these wells and from well 12.10.23.233a, which taps only the Chinle formation, have been plotted to show their characteristic chemical patterns (fig. 13). These diagrams show that the water from well 12.10.23.233 is not a simple mixture of water from the Chinle formation and the San Andres limestone. Therefore, the composition of water in this well must reflect a complex origin. This assumption is reasonable in view of the well's geographic and geologic position.

Although the composition of water from these wells differs for numerous reasons, some of the difference may be ascribed to the lithologic environment. The high concentration of sodium in water from well 12.10.23.233 indicates environmental differences at wells 11.10.8.111 and 12.10.23.233. The sodium probably was derived from the overlying Chinle formation.

The Chinle formation does not contain an abundance of sodium minerals, but it contains a type of clay which tends to release sodium ions into solution in exchange for other cations. Well 12.10.23.233 was drilled through about 800 feet of the Chinle formation. The log of this well indicates that the lower 120 feet probably contains deposits of this clay. The casing in this well is perforated throughout its length, which would allow mixing of water from the Chinle formation with water from the underlying San Andres limestone. That the waters mix is further supported by comparison of an analysis of a sample collected October 6, 1954, with other analyses of water from this well. The sample that was collected October 6 was characteristic of water from the Chinle formation. The well had been pumped only a few hours at the time the sample was taken, and it had not been pumped previously in the 1954 irrigation season. Notwithstanding this exception, it is likely that this well ordinarily

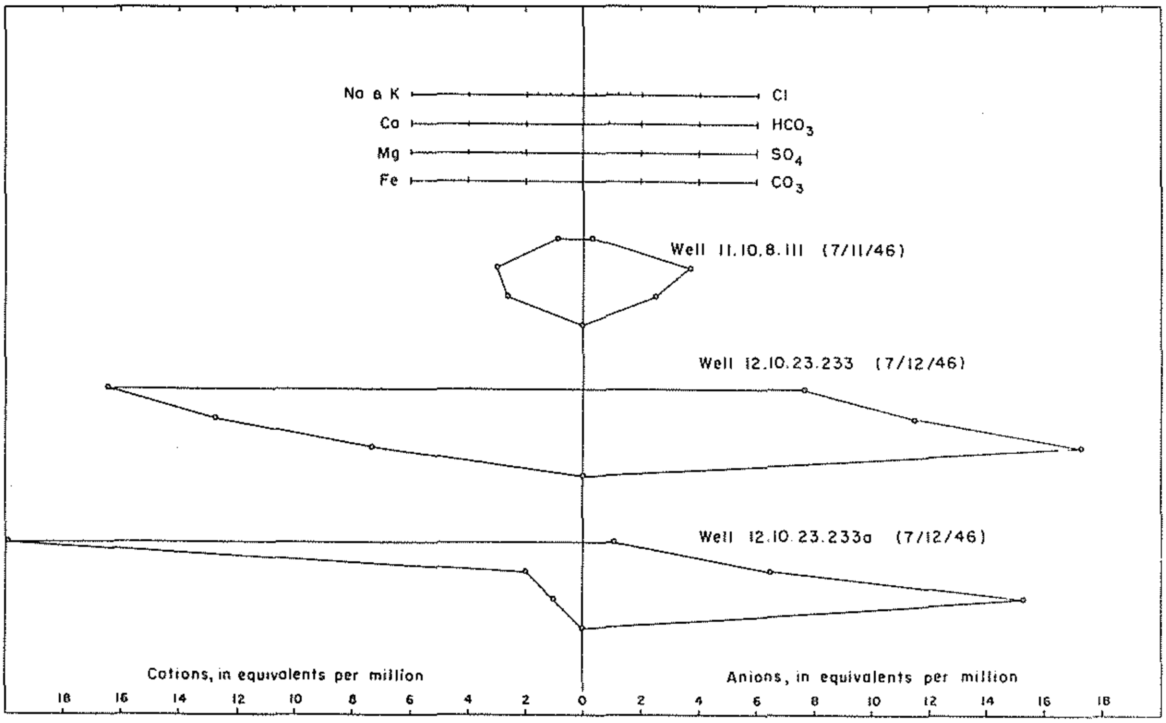


FIGURE 13. -- A graphic comparison of chemical analyses of water from wells 11.10.8.111, 12.10.23.233, and 12.10.23.233a, Valencia County, N. Mex.

yields water that is representative of ground water in the upper part of the San Andres limestone. The yield from the Chinle formation ordinarily will be an insignificant part of the total yield.

The high sodium concentrations in some waters from the San Andres limestone undoubtedly are due in part to the percolation of ground water from the Chinle formation, but several lines of evidence indicate that the general effect of interformational mixing is minor. One argument against extensive mixing is that the waters from these formations are incompatible chemically, and if they were mixed in the proportions necessary to account for the typical sodium concentration in water from well 12.10.23.233, a completely different composition of solute would have resulted. Ground water in the San Andres limestone moving out under the Chinle formation increases in sodium, calcium, and bicarbonate concentrations, a situation difficult to explain by interformational mixing of incompatible waters. If the large increase in sodium concentration in water beneath the Chinle formation is not due to interformational leakage from the Chinle formation, it must be due to ion exchange, because that is the only plausible explanation for the changes that take place in this environment.

The physical environment necessary for ion-exchange reactions of this magnitude calls for a special explanation. The unconformity between the Chinle formation and the San Andres limestone probably is the locale of these reactions. This contact is a rough, irregular surface. A karst topography was developed on the San Andres limestone before the Chinle formation was deposited. Subsequent faulting has resulted in an even more irregular contact. Moreover, it is possible that recently developed solution channels in the limestone are being partly filled with clay from the Chinle formation. The zone of contact between these formations, therefore, is a probable site for extensive ion-exchange reactions.

Artesian pressure affects the composition of water in parts of the San Andres limestone. The higher calcium concentration in water that has moved under the Chinle formation is due in part to artesian pressure. Water from well 12.10.23.233 is saturated, or perhaps slightly supersaturated, with calcium carbonate, relative to atmospheric pressure.

The dynamics responsible for the changing chemical quality of ground water in this formation probably come to equilibrium in the vicinity of well 12.10.23.233. A well drilled into the San Andres limestone in the SE¼ sec. 22, T. 14 N., R. 10 W., about 20 miles north of well 12.10.23.233, yields water that is strikingly similar in composition and salinity (tables 10 and 11) to that pumped from well 12.10.23.233. Furthermore, the composition of water pumped from well 12.10.23.233 has not changed with one exception, over a period of 9 years (table 10), unique for ground water in this area. The inference from these data is that well 12.10.23.233 yields water of the poorest quality in the San Andres limestone in this area, and, if the inference is correct, wells drilled into this formation farther from the outcrop area should yield water of similar quality.

The pattern of change in the quality of ground water in this area in the last decade, with major exceptions in the northern part of the valley, is fairly well defined. In general, the quality of water from wells nearest the San Andres outcrop tends to improve, and the quality of water from those farther from the outcrop tends to deteriorate. Water from wells 11.10.16.121 and 12.11.25.313 has improved in quality, but that from wells 11.10.4.211, 11.10.9.221, 12.11.10.431, and 12.11.15.341 has deteriorated. The quality of water from well 12.10.30.412, in an intermediate position, is erratic; at times the well yields water of better quality than is yielded at other times. Over a period of 10 years, however, water from this well trends toward a slightly poorer quality. These changes indicate that water is being drawn into the area of heavy pumping from several directions. Water of poorer quality is moving in from the northwest and northeast, but water of better quality is moving in from the southwest. The relative amounts moving from each direction is conjectural, but most of the water moves in from the southwest.

Although the overlying alluvium may contribute some water of good quality to the San Andres limestone, most of the inflow probably is derived from another source. For example, well 12.11.25.313, near the mouth of a stream that drains a large part of the Zuni uplift, yields water that has improved more in quality than that from any other well. The drainage area of this stream is largely on the outcrop of the San Andres limestone. Furthermore, the composition of water from well 12.11.25.313 is similar in many respects to water from other wells drilled into the San Andres limestone, where recharge from the alluvium is not possible. Thus, it is concluded that most of the recharge water of good quality moves along the dip slopes of the Zuni uplift.

Chinle Formation

The most characteristic feature of ground water in the Chinle formation is the high proportion of sodium ions in the solute making the water generally unsuitable for irrigation. Use of the water generally would result in the formation of a "black alkali" soil. If the salinity of the water is low, however, as of water from wells 10.9.23.134, 10.9.26.-433, 12.9.8.431, and 12.11.3.112a, the agricultural utility may be improved by adding gypsum to either the water or the irrigated soil. In general, however, the quality of water from the Chinle formation is too poor for economical treatment, and its use is best confined to watering stock.

The Chinle contains some briny water. The analysis of water from well 12.10.1.222 indicates 9,590 ppm of chloride but only 34 ppm of bicarbonate. The composition of this water is unusual. More data are necessary to interpret its history.

The data in table 10 probably are not representative of the composition of the water in this formation. The overall quality probably is worse than these data indicate. Some of the beds of sandstone should yield water of fair quality to wells, but the yields probably would be low because of the low permeability and poor recharge potential of these rocks.

Alluvium and Basalt

The pattern of quality of water in the alluvium and basalt is not well defined. The quality ranges widely within short distances and varies within short periods of time because the sources of recharge are numerous and because these sources may contribute water of different quality at different times. Moreover, the lithologic environment differs widely from place to place.

The discharge of Horace Springs (10.9.23.400) is the outflow from the alluvium and basalt at the lower end of the Grants-Bluewater area. This water is intermediate in composition and solute concentration to that within the Grants-Bluewater basin. If the discharge of Horace Springs consisted only of outflow from the Grants-Bluewater Valley, it might furnish a more valuable clue to the overall quality of water in the rocks of the valley. The outflow at these springs, however, includes that from the extensive Malpais Valley, which has at least twice the drainage area of the Grants-Bluewater Valley.

Water from Grants city well 3 (11.10.26.321), upgradient from the Malpais Valley, probably is more representative of the outflow from the Grants-Bluewater Valley. Water from this well has a higher salinity than water from most wells tapping the alluvium, and most of the increase in salinity is due to sodium ions. The higher concentration of solute may be due to mixing with ground water moving into the main valley from the north. If water from well 12.10.27.244 is representative of water moving in from the north, the analysis of water from well 11.10.26.321 indicates that far more water is moving down the Grants-Bluewater Valley than is moving in from the north.

Very little information is available on the major recharge sources of these rocks. The composition of the water in the alluvium and basalt of the Grants-Bluewater Valley is similar to that of some of the water in the underlying San Andres limestone, to that of the recharge from the Zuni uplift, and to that of some storm runoff in the Rio San Jose. The composition is not similar to that of either ground water or storm runoff from the Chinle formation or to the perennial flow in Bluewater Canyon.

The quality of water in the alluvium and basalt, such as in the vicinity of Bluewater Station, is locally superior to that in the underlying San Andres limestone. These differences in quality were striking at the time of data collection, but they may not be so pronounced at present because contamination from industrial waste may be spreading rapidly through the alluvium, as is indicated by analyses of water from well 12.11.14.213. The specific conductance, a measure of the ability to conduct an electric current, of this water rose in less than a year from 604 to 1,020 micromhos, and the nitrate concentration rose from 0.9 to 6.6 ppm. This well is a little more than a mile from a possible source of contamination. Plans for a different disposal of waste from this source have been formulated. If ground water has been contaminated from this source and the plans are put into operation, the quality of the shallow ground water should improve.

Relation of Chemical Quality of Ground Water to Use

The main chemical-quality factors that should be considered when evaluating water for irrigation include specific conductance; sodium-adsorption-ratio; amount of boron; and, under some conditions, bicarbonate content. It is not possible to classify water as suitable or unsuitable for irrigation solely on the basis of a chemical analysis, however. Other factors such as expected reactions in the soil solution, permeability and drainage of the soil to be irrigated, quantity of water to be applied, and boron and salt tolerances of the crops to be grown must be considered.

The U. S. Department of Agriculture (1958) has published a report on the soils of this area. The report states that saline soils were uncommon before ground water became the principal source of irrigation water. A number of soil types in this area are unsuitable for irrigation with the type of water available, but for one reason or another they are not farmed extensively.

The method used in this report for classifying waters for irrigation is based on salinity and sodium (alkali) hazards (U. S. Salinity Laboratory Staff, 1954). The salinity hazard is a function of the salinity, expressed as specific conductance, and the sodium hazard is a function of the sodium, calcium, and magnesium concentrations, expressed in equivalents per million. The latter function is called the sodium-adsorption-ratio (SAR) and is mathematically defined as:

$$SAR = Na^{+}/\sqrt{Ca^{++} + Mg^{++}/2}$$

All water for which analyses are available has been classified for irrigation use (fig. 14). These data show that the formation of saline soils is a real possibility under various farming conditions. It is to be noted, also, that some ground waters are apt to form alkali soils; however, this problem is not so serious as it appears. The waters presenting high sodium or alkali hazards are, for the most part, from the Chinle formation, which is an unlikely source of irrigation water.

The New Mexico Department of Public Health recommends for public water supplies the standards set forth by the Federal government (U. S. Public Health Service, 1946) for drinking water used by interstate carriers. Some of these limits, along with the corresponding concentrations in the public water supplies of the study area, are given in table 12. A comparison of these values shows that most of the municipal-water supplies of this area are defective in some respects. Of the four supplies tabulated, only one (Milan) conforms in all respects to the recommended standards. These diversities are not serious, but they might cause a mild temporary diarrhea in some individuals under certain conditions. Most of the wells that tap the principal aquifers yield potable water; however, because of local environmental factors, a few wells yield water that is impotable.

The requirements for industrial and commercial water are too varied for a simple discussion. It will suffice to state that the quality of ground water in this area is about average for the Southwest. Individuals interested in water for industrial and commercial enterprises should evaluate the chemical analyses in table 10, and decide whether a water supply suitable for their particular purpose is available.

Summary of Quality of Water

All water for which analyses are available has been classified for irrigation (fig. 14). The salinity hazard of most waters is high. The sodium or alkali hazard is low for all waters except for those from the Chinle formation. The Chinle formation, however, ordinarily does not yield enough water for irrigation. The agricultural utility of ground water in this area is neither the best nor the worst. This water, under good management, generally can be used without creating problem soils.

The municipal-water supply of Grants is very hard and the content of dissolved solids is too high to be desirable; and the sulfate concentration is high enough to impart an objectionable taste to the water.

The water of best quality in the San Andres limestone is that in the southwestern part of the Grants-Bluewater Valley. The alluvium contains some water of good quality in the vicinity of Grants, Milan, and Bluewater Station, but the supply may not be reliable and is subject to contamination from several sources, especially at Grants; therefore, it is no longer used for public supply at Grants.

The quality of water in Malpais Valley should be investigated, as the valley may be underlain in part by ground water of good or fair quality.

CONCLUSIONS

The Grants-Bluewater area was studied in order to learn the general availability and chemical quality of ground water and the probable effect of pumping on water levels.

The area is situated favorably for continued economic growth because 1) it is served by excellent rail and highway facilities; 2) it is near large reserves of minerals, such as uranium, fluorspar, pumice, and coal; 3) pine forests in the Zuni Mountains and Mount Taylor areas provide material for a wood-products industry; 4) irrigation agriculture in the fertile Grants-Bluewater Valley produces excellent vegetable crops, especially carrots; 5) forage on the high mesas and mountains supports large herds of livestock; and 6) Bluewater Reservoir, the Zuni Mountains, and Mount Taylor are popular recreational centers which attract thousands of visitors each year. Overall economic development depends, however, on the availability of large quantities of water, which is supplied largely from ground-water reservoirs. The supply of ground water in this area is greater than any that has been evaluated in any other part of northwestern New Mexico.

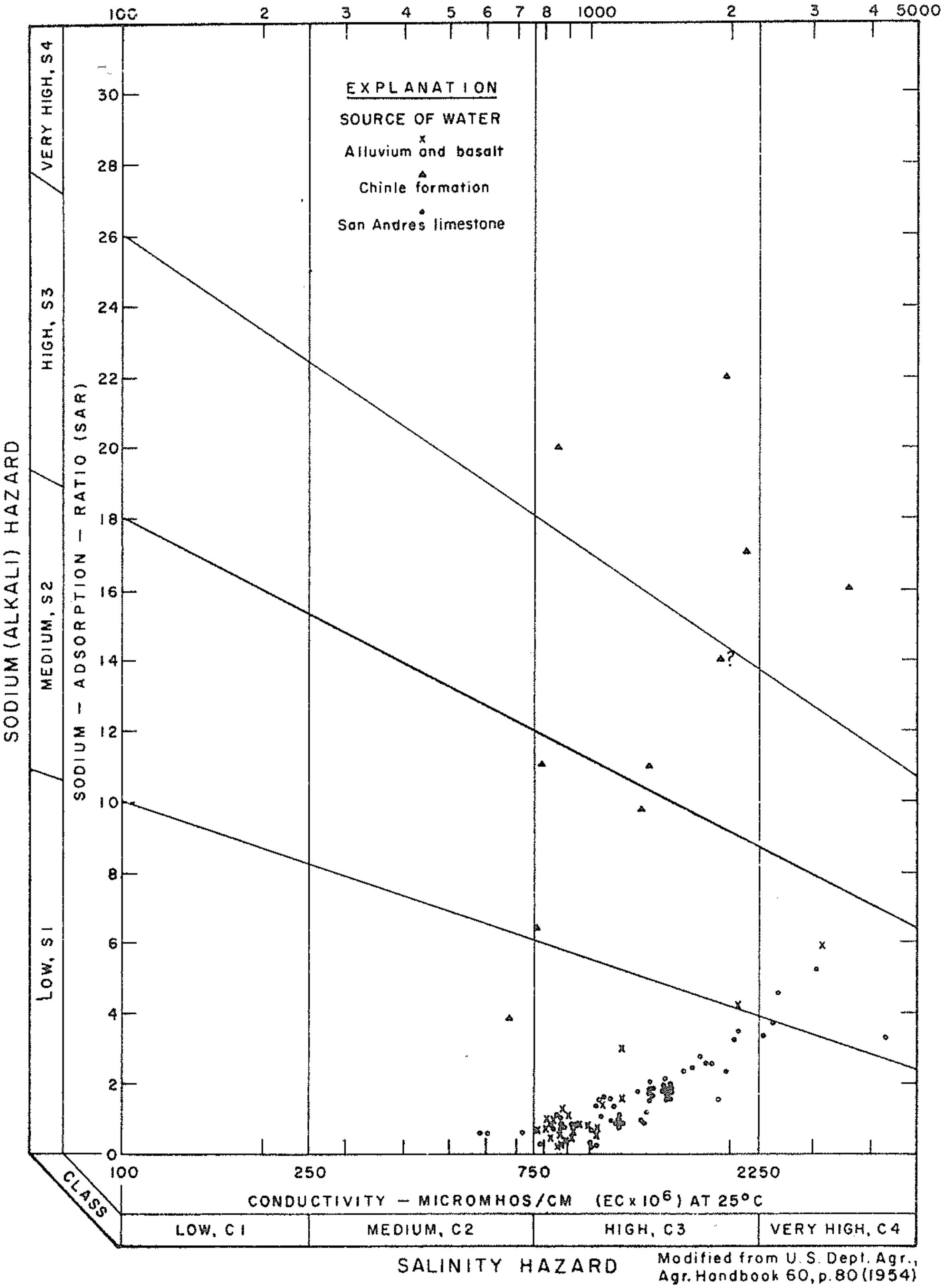


FIGURE 14. -- Classification of ground waters in the Grants-Bluewater area, Valencia County, N. Mex., for irrigation use, according to sodium adsorption ratio and conductivity.

The Glorieta sandstone and the overlying San Andres limestone which contains many interconnecting solution channels and cavernous zones form the principal ground-water reservoir or aquifer. Alluvium and basalt form a ground-water reservoir of secondary importance.

Most of the wells that tap the principal aquifer are completed in the San Andres limestone. However, as water is withdrawn from the San Andres, inflow from the Glorieta sandstone is induced.

Wells that tap the San Andres limestone range in depth from 100 to 980 feet; the majority range from 100 to 300 feet. The depth to water in the wells ranges from 20 to 250 feet.

The yields of wells that tap the San Andres limestone range from 500 to 2,800 gpm. Specific capacities range from 10 to 1,100 gpm per foot of drawdown; the average specific capacity is about 200 gpm per foot of drawdown.

The salinity of water in the principal aquifer varies within wide limits. The solute in the water consists largely of calcium, magnesium, and bicarbonate ions; but some of the water, especially where the aquifer is overlain by clays of the Chinle formation, also has high concentrations of sodium and sulfate. The water of best quality is that in a narrow belt between Bluewater and Milan. The concentration of dissolved solids in the water of this belt generally ranges from 350 to 750 ppm. In other parts of the aquifer, the concentrations of dissolved solids are as high as 2,200 ppm.

The chemical quality of water yielded by many wells that tap the San Andres limestone has changed in the last decade, and the quality will continue to change gradually, as ground water moves into the area of heavy pumping, because the quality varies widely in short distances. At some places the quality improves; at other places it deteriorates.

Grants, Bluewater, San Rafael, and several outlying housing projects and trailer courts are supplied with water from the San Andres limestone. Of these communities, Grants has water of poorest quality. It has a hardness of 671 ppm and contains 1,350 ppm of dissolved solids and 498 ppm of sulfate which imparts a disagreeable taste to the water.

Large quantities of water of inferior quality probably are available in the principal aquifer north, east, and south of the areas of current pumping. The water in these areas may not be chemically acceptable for domestic use and for many types of industrial use, without treatment. Also, the aquifer is progressively deeper to the north, east, and south. Despite the obstacles, these areas assure a large supply of water for the future.

Wells that tap the alluvium and basalt aquifer range in depth from 30 to 370 feet; the depth to water in the wells ranges from 10 to 120 feet. This aquifer yields as much as 1,000 gpm to wells. The specific capacity of only one was determined; it was 31 gpm per foot of drawdown. The largest yields, and also the water of best chemical quality in the alluvium and basalt, are obtained in the vicinity of Bluewater Station and Milan. Because the water table in the alluvium and basalt generally is shallow, the water is susceptible to bacterial contamination. For this reason, and because the yield was inadequate, the municipal wells at Grants that tap the alluvium and basalt have been abandoned.

The potential yield and the chemical quality of ground water in the alluvium and basalt in Malpais Valley, southeast of Grants, has hardly been explored. Further exploration in this valley may reveal at least local underground reservoirs containing large amounts of usable water.

Most, if not all, of the geologic formations in the Grants-Bluewater area yield adequate quantities of water for domestic and stock use, but much of the water in formations other than those forming the principal aquifers is of inferior chemical quality.

The Bluewater Underground Water Basin was declared by the State Engineer, as provided by law, on May 21, 1956 (New Mexico State Engineer Office, 1958), to regulate the use of ground water. Appropriation of ground water since that time has been permitted only to supplement existing surface-water rights. The number of irrigation wells in the area had increased from 7 in 1945 to a maximum of 23 in 1951. A few industrial and municipal wells had been drilled since 1951, and some of the irrigation wells had been converted to industrial and municipal supply. Industrial and municipal use of ground water has increased each year since 1951. This increase, however, has been compensated approximately by an equivalent decrease in irrigation use, so that the total amount of ground water pumped each year has remained almost constant at about 13,000 acre-feet a year. The rate of annual pumpage is not expected to decrease for 9 years at least.

Withdrawal of large amounts of ground water has caused water levels to decline significantly since 1946, when regular water-level measurements began. North of Bluewater, levels have declined 40 to 45 feet; from Bluewater southeast to near Grants, the levels have declined 18 to 20 feet. Ojo del Gallo, a spring which formerly discharged about 3,100 gpm, has ceased to flow because of the decline in water levels caused by pumping and extended drought. Water levels likely will continue to decline as long as large-scale pumping continues, because pumping of ground water is a new discharge that has been imposed upon an approximately stable ground-water system. The rate of decline should decrease as pumping continues, however, because water will be drawn into the area of heavy pumping from increasingly greater distances. If enough water is available in Bluewater Reservoir in some years to provide surface water for irrigation, the ground-water reservoir will be replenished temporarily to some extent from irrigation seepage, and pumping for irrigation will be reduced. Excessive precipitation for a year or two also might retard the downward trend of water levels, or even cause a temporary rise. On the other hand, an increase in use of ground water will accelerate the rate of decline of water levels. Continued pumping of ground water probably will affect further its natural discharge south and southeast of Grants and near McCartys.

The importance of the large supply of ground water in the Grants-Bluewater area to the economy of that area and to New Mexico in general can hardly be overemphasized. Therefore, a detailed investigation of this and adjoining areas would be desirable to 1) evaluate quantitatively the volume, accessibility, and chemical quality of the ground water; 2) learn more of the relation of ground water to runoff and spring discharge; 3) explore the possibilities of inducing ground-water recharge and the effects of induced recharge on downstream runoff and on chemical quality of ground water in the recharged areas; and 4) provide the factual basis for water-management programs to assure maximum benefits from water use.

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TABLES

TABLE 1

CLIMATOLOGICAL SUMMARY FOR STATIONS IN THE GENERAL VICINITY OF THE GRANTS-BLUEWATER AREA, VALENCIA AND MCKINLEY COUNTIES, N. MEX.

Station	Last complete year of record	Years of record	Altitude (feet)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Average monthly and annual precipitation (inches)																
Bluewater	1956	40	6,650	0.44	0.48	0.46	0.42	0.59	0.56	2.01	2.21	1.39	0.69	0.40	0.45	10.10
Grants	1955	9	6,500	.39	.20	.44	.38	.46	.57	1.69	2.47	.79	.30	.36	.26	8.31
San Fidel	1955	29	6,100	.38	.48	.46	.59	.85	.79	1.70	2.09	1.54	.67	.41	.49	10.45
Fort Wingate	1956	51	7,000	.91	1.31	1.04	.90	.59	.61	2.16	2.36	1.42	1.06	.73	.97	14.06
Laguna	1956	32	5,815	.37	.49	.45	.79	.64	.79	2.04	1.66	1.60	.65	.47	.66	10.61
Average monthly and annual temperature (degrees F.)																
Bluewater	1953	45	6,650	27.2	32.3	38.5	47.1	54.9	64.4	68.7	66.4	59.3	49.0	36.7	28.3	47.7
Grants	1954	9	6,500	30.7	36.0	40.8	51.5	58.8	67.9	73.3	70.3	64.6	53.6	39.2	32.7	51.6
San Fidel	1953	30	6,100	30.7	35.9	42.0	50.5	59.3	68.3	72.3	69.9	62.9	52.0	39.6	32.6	51.3
Fort Wingate	1956	28	7,000	31.3	35.0	39.9	48.0	56.0	65.1	69.8	67.4	62.2	51.4	40.9	32.7	50.0
Laguna	1956	24	5,815	33.2	37.8	44.1	52.4	60.5	70.1	74.3	72.7	65.6	54.3	42.4	33.4	53.4
Average monthly and annual evaporation rate (inches)																
Gamerco (Gallup), McKinley County	1928	7	6,750	1.52	2.75	5.67	8.77	12.95	15.69	12.49	10.52	9.13	6.99	3.52	1.39	91.39

TABLE 2

GAGED FLOW IN BLUEWATER CREEK NEAR BLUEWATER, VALENCIA COUNTY, N. MEX., 1913-56, ACRES IRRIGATED BY SURFACE WATER IN THE BLUEWATER-TOLTEC IRRIGATION DISTRICT, AND AMOUNT OF SURFACE WATER APPLIED TO IRRIGATED LANDS

(Location of gage: Lat. 35°17'50", long. 108°01'40", in W½SW¼ sec. 5, T. 12 N., R. 11 W., on left bank 2½ miles northwest of Bluewater and 8 miles downstream from Bluewater Dam. Drainage area, 235 square miles; runoff is regulated by Bluewater Reservoir. Records for 1913-30 from New Mexico State Engineer Tech. Rept. 7, rounded in accordance with Geological Survey standards. Records for 1931-56 from U. S. Geol. Survey Water-Supply Papers, and unpublished records.)

Calendar year	Flow past gage on Bluewater Creek: Acre-feet per calendar year	Acre-feet per water year 1/	Acre-feet during growing season (Apr-Sept)	Acres irrigated by surface water	Acre-feet of surface water applied to irrigated land
1913	6,290	6,030	5,370		
1914	10,800	10,830	3,680		
1915	28,400	27,480	18,580		
1916	I	40,200	11,210		
1917	3,490	7,210	2,100		
1918	4,810	4,750	1,060		
1919	I	I	I		
1920	N	N	N		
1921	I	I	4,380		
1922	1,540	1,550	384		
1923	10,400	8,830	4,840		
1924	7,110	8,790	1,800		
1925	3,140	2,740	384		
1926	24,460	24,020	11,030		
1927	23,770	24,550	14,210		
1928	2,900	2,700	2,420		
1929	4,390	3,880	3,340		
1930	8,200	8,750	7,030		
1931	3,800	4,150	3,560		
1932	12,230	10,800	10,230	3,720	6,031
1933	12,000	12,800	10,000	3,440	5,307
1934	4,370	4,980	3,890	2,490	2,050
1935	9,800	9,320	9,120	-	-
1936	11,370	11,390	10,380	2,740	-
1937	13,180	12,830	11,700	-	-
1938	12,800	12,710	11,020	3,080	-
1939	9,170	9,740	8,340	-	-
1940	4,600	4,760	4,200	-	-
1941	28,930	27,090	26,260	3,770	-
1942	20,560	20,700	16,720	3,920	-
1943	19,340	20,020	16,880	4,300	-
1944	8,020	9,210	7,380	2,100	-
1945	4,150	4,170	4,000	1,200 E	2,400 E
1946	414	315	181	0	0
1947	687	667	309	0	0
1948	8,630	8,410	7,990	1,500 E	4,630
1949	9,030	9,000	8,170	1,700 E	4,630
1950	838	1,090	417	0	0
1951	490	536	242	0	0
1952	7,480	7,140	6,870	2,000 E	4,500 E
1953	776	1,080	358	0	0
1954	684	679	410	0	0
1955	430	502	223	0	0
1956		251	104	0	0

E - Estimated.
I - Incomplete record.
N - No record.

1/ Water year is from October 1 of previous year to September 30 of year indicated.

TABLE 3

GENERALIZED STRATIGRAPHIC SECTION AND WATER-BEARING CHARACTERISTICS OF GEOLOGIC FORMATIONS IN THE GRANTS-BLUEWATER AREA, VALENCIA COUNTY, N. MEX.

System	Series	Subdivision	Thickness (ft)	Physical character	Water supply
QUATERNARY	Recent	Alluvium	0- 50	Valley-fill deposits of unconsolidated silt, clay, sand, and gravel.	Yields adequate quantities of water for stock and domestic supplies at many places and for irrigation locally.
	Pleistocene and Recent	Basalt	0- 200	Dense to vesicular black basalt, extruded as lava flows of varying thickness and extent.	Yields adequate quantities of water for stock and domestic supplies at many places.
	Pleistocene	Alluvium	0- 100	Valley fill deposits of sand, gravel, silt, and clay.	Yields adequate quantities of water for stock and domestic supplies at many places and for irrigation in favorable localities in valley.
QUATERNARY(?) AND TERTIARY	Pleistocene (?) and Pliocene	Basaltic rocks	-	Basaltic cinder cones, plugs, and dikes.	Ground-water possibilities not known.
TERTIARY	Pliocene	Extrusive rocks	0- 300	Basalt, rhyolite, and tuff breccia.	Yields water to springs at base of basalt flows at favorable localities along rims of high mesas.
CRETACEOUS	Upper Cretaceous	Mesaverde group, undivided	1,000-1,500	Gray to yellowish-buff silty shale and thin- to thick-bedded fine-grained sandstone, with some local coal beds.	Not utilized for water supply in the Grants-Bluewater area. Yields adequate quantities of water for stock and domestic supplies in adjacent areas.
		Mancos shale	700- 800	Platy, calcareous dark-gray marine shale, with some thick-bedded sandstones in lower part.	Not utilized for water supply in the Grants-Bluewater area.
	Upper and Lower (?) Cretaceous	Dakota sandstone	50- 100	Massive, medium- to coarse-grained yellowish-buff sandstone, locally with interbedded siltstone.	Not utilized for water supply in the Grants-Bluewater area. Yields adequate quantities of water for stock and domestic supplies in adjacent areas.
JURASSIC	Upper Jurassic	Morrison formation	300- 500	Claystone and siltstone, vari-colored, interbedded with fine- to medium-grained sandstone.	Not utilized for water supply in the Grants-Bluewater area. Yields adequate quantities of water for stock and domestic supplies in adjacent areas.
		San Rafael group, undivided	450- 700	Fine- to medium-grained, in part silty, vari-colored sandstone, siltstone, and claystone, with some limestone in lower part, and massive cross-bedded reddish-brown to orange sandstone in basal part.	Yields adequate quantities of water for stock and domestic supplies in northern and eastern parts of area.

TABLE 3 (continued)

System	Series	Subdivision	Thickness (ft)	Physical character	Water supply
TRIASSIC	Upper Triassic	Wingate sandstone	60- 100	Massive, cross-bedded reddish-brown to orange sandstone.	Yields adequate quantities of water for stock and domestic use.
		Chinle formation	1,400-1,600	Variegated siltstone and mudstone, with interbedded silty sandstone and some conglomeratic sandstone. The formation contains some thin limestones in the upper part, a thick sandstone unit near the middle, considerable sandstone in the lower part; locally, coarse-grained to conglomeratic sandstone occurs in the basal part.	Yields adequate quantities of water for stock and domestic supplies and for irrigation in some localities in the valley.
PERMIAN	Leonard	San Andres limestone	80- 150	Thick-bedded to massive light gray limestone, sandy limestone, and limy sandstone. The limestone strata are caverous in many localities.	Yields adequate quantities of water for irrigation, industrial, and municipal supplies.
		Glorieta sandstone	125- 300	Thick-bedded to massive, well-sorted medium-grained white to yellowish gray sandstone with limonitic flecks. Some interbedded siltstone in basal part.	Yields adequate quantities of water for irrigation, industrial, and municipal supplies.
		Yeso formation	350- 500	Orange to red siltstone and fine grained silty sandstone, with a few thin-bedded limestones in lower middle part, and a thick-bedded to massive cross-bedded fine-grained silty sandstone in basal part of formation. Some of the siltstone is gypsiferous.	Yields adequate quantities of water for domestic and stock supplies and at a few places for irrigation.
	Wolfcamp	Abo formation	500- 800	Dark brick-red to reddish-brown arkosic sandstone and siltstone, with numerous layers of conglomerate in lower part.	Not utilized for water supply in the Grants-Bluewater area, as the formation is deeply buried except in the Zuni Mountains.
PENNSYLVANIAN (?)		-	0- 480	Arkose and conglomerate, and a few thin arkosic limestone lenses and beds of shale.	Water-bearing properties not known.
PRECAMBRIAN			-	Granite, gneiss, metarhyolite, schist, and greenstone.	Water-bearing properties not known.

TABLE 4

RECORDS OF WELLS IN THE GRANTS-BLUEWATER AREA, VALENCIA COUNTY, N. MEX.

Location number: See explanation of well numbering system in text.

Altitude: Elevation above sea level of land surface at well. A, determined by aneroid; L, determined by spirit level survey, T, extrapolated from topographic map.

Depth of well: M, measured; otherwise reported.

Water level: Measured depths given to nearest one-tenth foot; reported depths given to nearest foot.

Yield: M, measured; E, estimated; otherwise reported.

Pumping level: Measured depths given to nearest one-tenth foot; reported depths given to nearest foot.

Type of pump: C, cylinder; J, jet; N, none; Su, submersible; T, turbine.

Type of power: B, butane; D, diesel; E, electric; G, gasoline; NG, natural gas; W, windmill.

Use of water: D, domestic; I, irrigation; Ind, industrial; Mu, municipal; S, stock; N, none. Symbol denotes intended use, past or future, generally at time of first measurement of water level.

Remarks: An, chemical analysis available; L, well log available.

Location number	Owner or name	Driller	Year completed	Altitude	Depth of well (ft)	Diameter of casing (in)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Stratigraphic unit	Water level: Depth below surface (ft)	Water level: Date of measurement	Yield: Rate (gpm)	Yield: Date of measurement	Pumping level: Depth below surface (ft)	Pumping level: Date of measurement	Type of pump	Type of power	Use of water	Remarks
9. 9. 3.331	Sidney S. Gottlieb	Turner Drlg.Co.	1946	6,702L	650	6	Sandstone	Entrada(?) ss.	350	1947	20	1947	-	-	C	G	S	
5.214	do.	do.	1951	6,516L	210	6	Red sandstone	Wingate(?) ss.	125.2 124.3	5-27-56 11-13-57	6	1956	-	-	C	W	S	L
29.224	R. B. Candelaria	do.	-	6,630A	-	7	-	Bluff(?) ss.	224.1 225.0	12-28-55 11-13-57	-	-	-	-	C	G	S	
9.10.10.414	Alfredo Mirabal	-	-	6,519L	105M	8	-	-	84.2 91.0	12- 3-48 11-13-57	-	-	-	-	C	W	S	
15.212	do.	-	-	6,529L	164M	8	-	-	99.6 101.4	1-21-56 7-27-56	-	-	-	-	C	W	S	
33.110	do.	Turner Drlg.Co.	1942	6,760A	347M	6	-	San Andres(?) ls.	325.4 327.3	12-28-55 11- 6-57	-	-	-	-	C	W	S	
10. 9.17.113	Sidney S. Gottlieb	do.	1945	6,439L	76M	7	Alluvium	Alluvium	41.9 43.4	6-14-49 11-12-57	4M	11- 7-57	-	-	C	W	S	An; L
21.222	do.	do.	1949	6,399L	70	6	Basalt	Basalt	47.5 47.6	12- 8-50 11-12-57	3	11- 7-57	-	-	C	W	S	
21.223	do.	do.	1954	6,392L	202	14	Basalt and gravel	Alluvium and basalt	-	-	-	-	-	-	N	-	N	Oil test. Upper 202 ft. drilled by Turner Drlg. Co. Log of this part of hole available. Total depth of test well 4,913 ft.
21.444	do.	do.	1949	6,400T	80	6	Red sandstone	Entrada ss.	44.0 44.6	12-12-50 7-31-56	10	1950	-	-	C	G	S	
23.130	do.	do.	1948	6,330A	70	-	-	-	38.8	6-14-49	-	-	-	-	N	-	N	Test hole, uncased.
23.134	do.	do.	1950	6,334L	1,035	12	Red beds	Chinle fm.	+ .2 14.8	12-13-50 11-13-57	150	1950	180	1950	T	-	I	An; L; flow of 5 gpm when completed; reported to yield 100 gpm from a depth of 465 ft. before deepening.
23.443	do.	do.	1948	6,280T	30	7	Alluvium	Alluvium	8.3	6-14-49	8	1949	-	-	J	E	D	
23.443a	do.	do.	1951	6,280T	33	7	Basalt	Basalt	-	-	-	-	-	-	J	E	D	L
26.224	do.	do.	1936	6,275L	100	6	do.	do.	8.8 8.7	10- 3-46 8- 3-56	-	-	-	-	C	W	S	
26.433	do.	do.	1947	6,347L	965	14	Red sandstone	Chinle fm.	21.7 22.0	1- 4-51 11-13-57	175M	1951	-	-	T	E	I,S	An
28.142	Maria Payaso	-	1947	6,409L	30M	-	Alluvium	Alluvium	29.3 29.0	10-17-50 9-26-55	-	-	-	-	N	-	D,S	Dug well with bucket lift. Caved Nov. 1957.
29.132	Sidney S. Gottlieb	Turner Drlg.Co.	1944	6,455L	80	7	do.	do.	60.8 62.4	6-14-49 11-13-57	-	-	-	-	C	W	S	
31.324	do.	do.	1949	6,484L	165	7	do.	do.	71.6 74.8	6-14-49 11-12-57	8	1949	-	-	C	W	S	
10.10. 3.433	Joe Padilla	-	-	6,460T	17M	-	do.	do.	9.8 16.0	2- 3-47 2- 8-56	-	-	-	-	-	E(?)	D	4x6 ft. dug well, not curbed; went dry in 1956.
3.433a	San Rafael Village	K. A. Huey	1952	6,470T	148	6	Yellow sandstone	San Andres ls.	18 25.8	5- 4-52 11- 6-57	-	-	-	-	T	E	Mu	An; L
10.322	Rosalio Candelaria	-	1954	6,460T	-	10	-	-	23.6	7-27-56	-	-	-	-	N	-	N	
10.433	Elfego Barela	E. T. Hoard	1953	6,450T	200	18	-	-	21.4	7-27-56	500	1953	-	-	T	B	I	
15.124	Ted Ortiz	Oscar Carter	1956	6,462T	109	8	Sandstone	Chinle(?) fm.	32.5	7-25-56	300	1956	-	-	T	G	I	
15.344	Eddie Chavez	John Lowry	1956	6,450T	554	-	-	-	23.7	7-25-56	-	-	-	-	N	-	N	Irrigation test hole, uncased.
22.210	Charles Boren	N. H. Wade	1958	6,455T	70	6	Gravel	Alluvium	23	8-19-58	-	-	-	-	-	-	D	L
22.211	R. D. Worthen	R. D. Worthen	1952	6,455T	32	6	Fine sand	do.	27	7-25-56	-	-	-	-	C	E	D	
22.211a	do.	do.	1953	6,455T	130	8	do.	do.	26.2	7-25-56	150	1956	-	-	T	G	I	L
24.212	Sidney S. Gottlieb	-	1955	6,445T	70	4	Alluvium	do.	33.0	11-13-57	3	1957	-	-	J	G	S	
25.114	do.	-	1955	6,440T	40	4	do.	do.	24.9	11-12-57	-	-	-	-	N	-	N	

TABLE 4 (continued)

Location number	Owner or name	Driller	Year completed	Altitude	Depth of well (ft)	Diameter of casing (in)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Stratigraphic unit	Water level: Depth below surface (ft)	Water level: Date of measurement	Yield: Rate (gpm)	Yield: Date of measurement	Pumping level: Depth below surface (ft)	Pumping level: Date of measurement	Type of pump	Type of power	Use of water	Remarks
12.10.12.433	G. P. Roundy	Turner Drlg.Co.	1945	6,625T	100	8	Alluvium	Alluvium	58.6 58.1	11-30-55 7-25-56	-	-	-	-	C	W	S	
14.212	do.	Tom Allen	1945(?)	6,621L	-	6	-	-	-	-	1	1956	89.3	7-25-56	C	W	S	Water level in abandoned well 15 ft. SW, 50.1 ft., 7-25-56.
20.333a	Fred Freas	Howard Sheets	1957	6,570T	275	10	Limestone	San Andres ls.	118.4 124.4	2-13-57 8-17-57	-	-	-	-	N	-	N	L; bailed at 30 gpm; no appreciable drawdown.
23.233	T.A. Morris & Son	Aubrey Lyons	1945	6,592L	865	20	Sandstone	do.	115.6 147.6	2-26-46 8- 1-57	1,900	1946	169.2	6-22-51	T	D	I	An; L
23.233a	G. P. Roundy	Turner Drlg.Co.	1944	6,594L	500	10	-	Chinle fm.	75	7-11-46	-	-	-	-	C	W	S	An; reported to have been test pumped at 300 gpm.
26.242	Homestake-Sapin Partners	H. P. Doty	1958	6,595T	980	12	-	San Andres ls.	133.8	5-22-58	1,550	5-21-58	165	5-21-58	T	E	Ind	An; L
26.322	Homestake-New Mexico Partners	C. T. Henderson	1950	6,573L	400	20	-	Chinle fm.	70.9	5-26-56	-	-	-	-	Su	E	D	Original depth 844 ft.; casing collapsed at 400 ft. during pumping test.
26.322a	do.	do.	1955	6,572L	870	20	Sandstone	San Andres ls.	122.4 124.4	10-13-55 11-14-57	-	-	-	-	T	E	I	An; L
27.244	Tom Morris	Turner Drlg.Co.	1945	6,574L	371M	6	-	Alluvium	90.5 88.6	7-25-56 2-13-57	-	-	-	-	C	E	D,S	An
27.333	Stanley & Card	Roscoe Moss	1949	6,557T	551	20	Limestone	San Andres ls.	87.0 103.7	4-18-50 4-12-58	1,500E	10- 2-56	120.2	10- 2-56	T	E,NG	I	An; L
27.431	W.A. Murray	C.T. Henderson	1955	6,567L	584	16	Sandstone	do.	112.2 117.7	10-15-55 10- 2-56	-	-	156.0	7-17-56	T	D	I	An; L
29.434	Stanley & Card	Turner Drlg.Co.	1944	6,552T	152	16	Alluvium	Alluvium	65.5 98.7	10-14-44 2-13-57	1,000E	6-28-56	101.2	8-18-49	T	D	I	An; L; test hole drilled to 205 ft.
29.434a	do.	Roscoe Moss	1948	6,554T	398	18	-	San Andres ls.	84.7 101.2	2-15-51 2-13-57	1,716M	5-11-48	107.0	8- 1-56	T	E	I	An; L
30.112	The Anaconda Co.	E.A. Tietjen	1929±	6,590T	280	6	Sandstone	do.	108.0 143.1	2- 3-47 6-28-56	-	-	125.1	2-11-55	C	W	D,S	An
30.242	Jack Freas	do.	1930±	6,569T	160	5	Sand and gravel	Alluvium	88.4 106.7	5-10-46 2-11-55	-	-	108.9	10- 8-53	C	G	D,S	An; L
30.332	Hardenburg Commissary Co.	-	-	6,585T	230	8	-	San Andres ls.	106.5 111.3	2- 4-47 2-10-49	375	1950	-	-	T	E	D,I	Old oil-test hole. Cleaned out and cased to 230 ft. in 1948 by Turner Drlg. Co.
30.333	E.E. Hardin	B. J. Brooks	1915	6,591T	175	6	Sandstone	do.	-	-	-	-	-	-	C	W	D	
30.412	Fred Freas	Turner Drlg.Co.	1945	6,578L	225	16	do.	do.	90.0 112.6	2-26-46 2-13-57	1,745E	2-10-50	128.8	8- 1-56	T	E	I	An; L
30.421	Milton Harding	do.	1946	6,576T	245	14	Sandrock and shells	do.	88.4 118.8	2-26-46 2-13-57	1,110M	6- 4-47	121.4	6- 5-56	T	E	I	An; L
30.433	Fred Freas	-	-	6,572T	135	-	Sandstone	do.	-	-	-	-	-	-	-	-	N	An
31.211	Bar-X Trailer Lodge	E. O. Cleaver	1957	6,575T	175	8	-	do.	121.9	11-17-57	50	1957	-	-	S	E	D	L
32.111	The Anaconda Co.	L. G. Stearns	1946	6,566T	253	20	Sandstone	do.	82.1 112.5	2-26-46 2-13-57	1,520M	8-25-52	119.5	10- 2-56	T	E	I	An; L
32.211	Eugene Chapman	E. A. Tietjen	1909	6,555T	135	5	Gravel	Alluvium	75.5	1-4-47	-	-	-	-	C	W	D,S	
33.444	Stanley & Card	Turner Drlg.Co.	1943	6,542T	195	6	-	Chinle fm.	-	-	25E	1943	-	-	C	E	D	An; L
34.214	W. A. Murray	C.T. Henderson	1951	6,558T	275	12	-	do.	81.8	10- 2-56	500E	-	-	-	C	W	D	An; former irrigation well.
34.412	Bruce Church	L.G. Stearns	1952	6,557L	978	16	-	Chinle fm. & San Andres ls.	101.4	2-13-57	-	-	-	-	T	D	I	An; L
12.11. 3.112a	F. M. Gibbs	N. H. Wade	1957	6,700T	200	7	Sandstone	Chinle fm.	63.8	1-28-58	-	-	-	-	Su	E	D	An; L
3.342	C. M. Gibbs	Turner Drlg.Co.	1944	6,660T	180	4	-	do.	126.6	8-31-56	-	-	-	-	Su	E	D	
4.243	W.C. Andrews	E.A. Tietjen(?)	-	6,663L	64	6	-	Chinle fm.(?)	-	-	-	-	-	-	C	W	D,S	
5.343	Church and Hardin	L. G. Stearns	1946	6,710T	255	-	Sandstone	Chinle fm.	170	2-27-46	225	2-23-46	-	-	N	-	N	L
5.413	J.C. Church	Turner Drlg.Co.	1948	6,710T	365	8	-	do.	192.0 237.2	2-11-49 2-12-57	-	-	-	-	N	-	N	L
9.114a	do.	do.	1948	6,662T	523	18	Limestone	San Andres ls.	136.1 175.5	2-11-49 2-12-57	-	-	-	-	N	-	N	An (sample from 145 to 178 ft. during drilling)
9.221	do.	L.G. Stearns	1945	6,649L	500	20	Sandstone	do.	115.7 172.3	2-27-46 2-11-57	-	-	-	-	N	-	N	L; equipped with water level recorder in 6-in. casing.
9.424	Geo. W. Rowley	Turner Drlg.Co.	1946	6,641T	500	16	do.	San Andres ls. & Yeso fm.	93.8 134.5	5-10-46 2-12-57	-	-	-	-	N	-	N	An; L; abandoned irrigation well.
10.334	J. W. Price	L.G. Stearns	1952	6,636L	464	18	Limestone	San Andres ls.	127	2- 51	2,500	1954	-	-	T	E	I	An; L

TABLE 4 (continued)

Location number	Owner or name	Driller	Year com-pleted	Altitude	Depth of well (ft)	Diam-eter of casing (in)	Principal water-bearing bed: Character of material	Principal water-bearing bed: Stratigraphic unit	Water level: Depth below sur-face (ft)	Water level: Date of measure-ment	Yield: Rate (gpm)	Yield: Date of measure-ment	Pumping level: Depth below sur-face (ft)	Pumping level: Date of measure-ment	Type of pump	Type of power	Use of water	Remarks
12.11.10.344	J.C. Church	Turner Drlg.Co.	1948	6,636T	378	8	Sandstone	San Andres ls.	121.7	4- 6-48	-	-	-	-	T	E	D,I	L
10.411	Claude M. Bowlin	Charles Barnes	1938	6,650T	216	4	-	Chinle fm.	118.3	5-10-46	-	-	-	-	N	-	N	Well went dry in 1953.
10.411a	do.	J. H. Wright	1951	6,640T	238	6	-	do.	160	10- 55	-	-	-	-	C	E	D	
10.431	Burton C. Johns	Howard Sheets	1945	6,635L	500	14	Yellow sand	San Andres ls.	103.7 169.0	2-27-46 9- 5-57	2,110M	6- 5-47	-	-	T	E	I	An; L
11.334	Duane Berryhill	Turner Drlg.Co.	1946	6,632A	150	8	-	Alluvium and basalt	121.6	6-27-56	-	-	-	-	J	E	D,S	An
14.213	do.	Cecil Schrader	1949	6,605L	115	4	Sand, gravel	do.	98.3 100.5	2- 8-50 2- 6-56	-	-	-	-	N	-	N	An; test hole.
14.311	Fred W.Freas	-	-	6,625T	140	6	do.	do.	-	-	-	-	-	-	N	-	N	An; L; well destroyed by highway construction 1953.
14.331	G. P. Roundy	Hubbell Bros.	1955	6,615T	130	6	-	do.	-	-	-	-	-	-	J	E	D	An
15.111	John Church	Turner Drlg.Co.	1944	6,635T	200	7	-	Chinle fm.	116.2	3-11-47	-	-	-	-	C	-	N	L
15.211	G. P. Roundy	J. F. Kimmell	1954	6,632T	450	16	Sandstone	San Andres ls.	156.5	2-13-57	2,000E	7-19-56	175.3	7-19-56	T	E	I	An; L
15.214	do.	Bert Brooks	-	6,630T	98	4	Sand and gravel	Alluvium	80	1944	-	-	-	-	N	-	N	L; well abandoned.
15.223	A.T.&S.F. Railroad	Gus Mulholland	1906	6,630T	735	12	Sandstone	San Andres ls.	120	1906	60	1906	120	1906	N	-	N	L; well abandoned about 1935. Plugged back to 660 ft.
15.321a	Harmon & Reid	L.V.Fitzwater	1948	6,631L	178	-	-	do.	109	12- 3-49	1,900M	8-19-49	-	-	T	E	I	Affected by pumping well 12.11.10.334.
15.341	Edward Freas	Turner Drlg.Co.	1946	6,627T	457	14	Sandstone	Glorieta ss.	106.1 149.4	2- 4-47 2-13-57	-	-	-	-	N	-	N	An; L; drilled to 300 ft. depth in Aug. 1946; deepened to 457 ft. in Oct. 1951.
15.422	Myerick Bros.	Oscar Carter	1930	6,625T	137	4	-	Chinle fm.(?)	92	10-13-44	-	-	-	-	C	W	D	L
16.230	E.B. Bowlin	Henry Brock	-	6,640T	180	6	-	Yeso fm.(?)	123.7	2- 3-47	-	-	-	-	C	W	S	An; L
20.422	J.F. Neilson	Mr. Brasher	1946	6,670A	310	18	Sandstone	do.	244.0 275.2	1- 3-47 2-13-57	-	-	-	-	C	E	S	An; L
22.144	T.J. McNeill	T.J. McNeill	1906	6,640T	376	6	-	-	110	10-13-44	-	-	-	-	C	G	S	
22.230	J.F. Neilson	-	1902	6,615T	170	6	-	Glorieta ss.(?)	100	10-12-44	-	-	-	-	C	W	S	
22.234	Church of Latter Day Saints	E.A. Tietjen	-	6,615T	260	8	-	San Andres ls.	77.1 91.4	5-10-46 12- 3-46	-	-	-	-	S	E	Mu	An; serves as muncipal supply well for Bluewater village. Deepened by Turner Drlg.Co.
22.242	J.F. Neilson	do.	1940	6,614T	298	8	Sandstone	do.	90	10-12-44	-	-	-	-	C	W	S	L
22.322	Geo.W.Rowley	Turner Drlg.Co.	1941	6,670T	583	8	-	-	130	10-20-44	-	-	-	-	C	W	S	An
22.414	Hassell	-	1946	6,629T	544	20	-	San Andres ls.(?)	110.6 149.5	2-27-46 2-19-53	-	-	-	-	N	-	N	Well deepened from 520 ft. to 544 ft. spring 1948.
22.420	E.A. Tietjen	E.A. Tietjen	1914	6,615T	120	12	Sandstone	San Andres ls.	60	1914	-	-	-	-	C	W	D,S	An
22.444	G.P. Roundy	do.	1909	6,614T	300	8	do.	do.	60	10-12-44	-	-	-	-	C	W	S	L
23.111	do.	E.T. Hoard (?)	-	6,610T	1,048	16	-	-	88.6	7-20-56	-	-	-	-	Su	E	S	Yield insufficient for irrigation well.
23.231	do.	Turner Drlg.Co.	1944	6,606T	300	8	-	San Andres ls.	69.5 71.6	1- 3-47 11- 4-57	-	-	-	-	C	W	S	An; L
23.333	do.	Ernest Boardman	1950	6,620T	350	16	-	-	-	-	15	1957	-	-	N	-	N	Yield insufficient for irrigation well.
24.233	The Anaconda Company	Howard Sheets	1955	6,613L	386M	16	-	San Andres ls.	157 156	1-14-55 1-13-56	2,100M	2- 7-55	224	2- 7-55	T	E	Ind	An
24.334	Peter Chalamidas	Mr. Meyers	1953	6,598T	250	6	-	do.	160	1953	18	1953	-	-	Su	E	D	An
24.334a	do.	Turner Drlg.Co.	1953	6,595T	502	10	Limestone	do.	160	1953	-	-	-	-	Su	E	D	L
24.411	The Anaconda Company	Howard Sheets	1951	6,612L	360	12	do.	do.	149.3 161.4	2-18-53 2- 8-56	600	7-18-56	155.3	2-11-55	T	E	Ind	An; L
24.424	do.	E.A. Tietjen	-	6,590T	-	5	-	-	110.4	5-10-46	-	-	-	-	C	W	S	
25.122	do.	Turner Drlg.Co.	-	6,595T	260	8	Limestone	San Andres ls.	48.3	4- 6-48	-	-	-	-	T	E	D	An; well deepened from 140 ft. to 260 ft. April 1, 1948
25.122a	do.	-	-	6,595T	135	6	-	-	119.5 119.8	7- 46 9-17-56	-	-	-	-	C	W	S	
25.213	do.	L.G. Stearns	1946	6,583T	236	18	Limestone	San Andres ls.	106.8 129.5	2- 3-47 2-16-56	2,170M	8-26-52	138.8	2-13-57	T	E	Ind	An; L
25.214	do.	Turner Drlg.Co.	1945	6,581T	238	18	do.	do.	100.2 132.6	2-27-46 2-13-57	1,800E	8-27-53	137.0	6-14-55	T	E	Ind	An; L
25.313	Harmon & Reid	do.	1946	6,605T	365	18	do.	do.	124.5 150.2	2- 3-47 2-13-57	2,000M	6- 4-47	-	-	T	G	I	An
26.224a	G. P. Roundy	Oscar Carter	1954	6,606T	199M	6	-	-	158.1	7-19-56	-	-	-	-	Su	E	D	
26.244	do.	T.J. McNeill	1912	6,605T	200	6	Sandstone	Glorieta ss.	-	-	-	-	-	-	C	W	D,S	Well deepened from 165 ft. to 200 ft. in 1954.
26.424	do.	Hubbell Bros.	1952	6,605T	225	6	-	-	160.1	10- 3-56	-	-	-	-	C	W	S	
27.222	Harold Prewitt	Turner Drlg.Co.	1936	6,630T	170	6	Sandstone	Glorieta ss.	156.1 179.3	2- 3-48 2- 7-56	-	-	-	-	C	W	S	
28.222	J.E. Neilson	E.A. Tietjen	1911	6,710T	212	6	-	do.	-	-	-	-	-	-	C	W	S	Water encountered at 210 ft. when well was drilled.

* Hand-dug well with no casing.

TABLE 5

RECORDS OF SPRINGS IN THE GRANTS-BLUEWATER AREA, VALENCIA COUNTY, N. MEX.

Explanation of Column Headings

Location number: See explanation of well-numbering system in text.
Altitude: Elevation above sea level of land surface at spring. L, determined by spirit level survey; T, extrapolated from topographic map.
Yield: M, measured; E, estimated; otherwise reported.
Use of water: D, domestic; I, irrigation; S, stock.
Remarks: An, chemical analysis available.

Location number	Owner or name	Altitude	Topographic situation	Principal water-bearing bed: Character of material	Principal water-bearing bed: Stratigraphic unit	Yield: Rate of flow (gpm)	Yield: Date of measurement	Use of water	Remarks
10. 9. 6.442	Sidney Gottlieb	6,401L	Valley floor	Lava flow	Basalt	0.5E	5-13-58	S	An
23.400	Horace Springs	6,276L	do.	do.	do.	2,000E	5-13-57	D,S,I	Flow issues from a series of openings along and adjacent to Rio San Jose.
10.10. 3.423	Ojo del Gallo	6,449L	Valley floor below fault scarp	Limestone and sandstone	San Andres ls.	-	-	S,I	An; formerly used to irrigate about 1,200 acres of land. Spring pool dry since 1953.
10.11.17.231	Malpais Spring	7,430T	Valley	Lava flow	Basalt	70E	12-12-33	S	An; formerly used for locomotives on lumber railroad.
12.11.18.142		1	Canyon floor	Alluvium	Alluvium	0.75M	3-24-49	S	Formerly used for domestic supply.

TABLE 6

LOGS OF WELLS AND TEST HOLES IN THE GRANTS-BLUEWATER AREA, VALENCIA COUNTY, N. MEX.

(The following logs of wells and test holes were furnished by drillers, land owners, industrial companies, and other organizations. In general, the lithologic terminology is that of the persons who furnished the information. The rocks termed "malpais" in many of the logs are the same as the basalt flow rocks described elsewhere in this report. The stratigraphic correlations were made by E. D. Gordon. Many of the logs have been rearranged slightly for clarity and uniformity of presentation.)

Stratigraphic unit and material	Thickness (feet)	Depth (feet)
12.10.26.242 Homestake-Sapin Partners		
Casing record: 902 feet of 16-inch casing, cement in place from bottom to surface. 87 feet of 12 3/4-inch shutter screen set below bottom of 16-inch casing.		
QUATERNARY SYSTEM:		
Top soil (clay, sand, and gravel)	30	30
Red clay and gravel	90	120
TRIASSIC SYSTEM:		
Chinle formation:		
Clay, red	90	210
Shale, red; traces of blue shale	5	215
Shale, red; some hard white rock	5	220
Shale, red and gray	5	225
Shale, red and blue	10	235
Shale, red and gray	5	240
Clay or shale, red	35	275
Sandstone, gray, hard	25	300
Sandstone and shale, red	85	385
Clay and sandstone, gray	10	395
Shale, clay, and sandstone	30	425
Shale and clay	15	440
Shale and limestone	5	445
Clay and sandstone	35	480
Clay and shale	15	495
Clay and sandstone	5	500
Clay		500
Sandstone, white and blue; some red clay	20	520
Sandstone, white; some blue clay	15	535
Clay, gray, and hard shale	35	570
Shale and sandstone	10	580
Clay and shale, gray	20	600
Shale and sandstone	45	645
Shale, sandstone, and limestone	5	650
Shale, purple, and gray sandstone	15	665
Shale and gray clay	5	670
Shale, gray, and sandstone	10	680
Shale, gray and red	40	720

TABLE 6 (continued)

Stratigraphic unit and material	Thickness (feet)	Depth (feet)
12.10.26.242 Homestake-Sapin Partners (continued)		
TRIASSIC SYSTEM (continued)		
Chinle formation (continued)		
Clay and shale, varicolored, and sandstone ...	115	835
Shale, gray and brown	5	840
Shale, purple and gray	5	845
Shale, purple, gray, and red; and red sandstone	5	850
Clay, light-red, and gray sandstone	5	855
Shale, gray, and sandstone	5	860
Shale, red and gray	20	880
Shale, gray, and sandstone	10	890
Shale, purple and gray, and sandstone	5	895
Sandstone and gray shale	5	900
Shale, purple and red, and sandstone	35	935
Shale, gray, and sandstone	25	960
Shale, gray and red, and boulders	10	970
Shale, purple, red, and gray, and sandstone ..	5	975
PERMIAN SYSTEM:		
San Andres limestone:		
Lost circulation	5	980
12.10.26.322a Homestake-New Mexico Partners		
QUATERNARY SYSTEM:		
Valley fill:		
Sand, grayish-orange, fine to coarse, rounded; chiefly frosted, quartz grains; some grayish-orange clay	10	10
Sand, grayish-orange, fine to coarse, rounded; chiefly frosted quartz	20	30
Sand, light-brown, fine to coarse, rounded; light-brown, frosted quartz	10	40
Sand, light-brown, fine to very coarse, rounded to subrounded; chiefly quartz	10	50
Sand, light-brown, fine to very coarse, 90 percent rounded to angular quartz grains; less than 10 percent light-olive-gray limestone fragments	10	60
Sand, grayish-orange, fine to very coarse, 30 percent subrounded to angular quartz; some medium to very coarse rock fragments; obsidian, and fossil fragments	10	70
Sand, grayish-orange, fine to coarse with granules, quartz 50 percent subrounded to angular quartz grains; some fossils	10	80
Sand, grayish-orange, fine to coarse with granules, 60 percent rounded to angular, frosted quartz grains; some subrounded shell fragments	10	90

TABLE 6 (continued)

Stratigraphic unit and material	Thickness (feet)	Depth (feet)
12.10.26.322a Homestake-New Mexico Partners (continued)		
QUATERNARY SYSTEM (continued)		
Valley fill (continued)		
Sand, grayish-orange-pink, fine to coarse with granules; 30 percent rounded to subangular, frosted quartz grains; some subrounded shell fragments	10	100
Sand, silty, grayish-red; sand is medium to very coarse with granules; 30 percent rounded to angular, frosted quartz	10	110
TRIASSIC SYSTEM:		
Chinle formation:		
Shale, sand, and gravel; 65 percent grayish-red shale; 20 percent fine to coarse, rounded to subangular quartz; 15 percent subrounded to angular gravel	10	120
Shale, sand, and gravel; 70 percent grayish-red shale; 15 percent medium to coarse, rounded to angular, frosted quartz; 15 percent subrounded to angular gravel	20	140
Shale, sand, and gravel; 60 percent grayish-red shale; 20 percent fine to medium, subrounded quartz, sand; 20 percent subrounded gravel	10	150
Shale, sandstone, and gravel; 60 percent grayish-red shale; light-gray, very fine-grained sandstone with subrounded, frosted quartz grains; 20 percent subrounded gravel	10	160
Sandstone, shale, and gravel; 50 percent light-gray, very fine- to fine-grained sandstone with subrounded grains; 25 percent grayish-red shale; 25 percent subrounded gravel	10	170
Shale and sandstone; 80 percent grayish-red shale; 20 percent very fine to fine and subrounded frosted quartz grains	10	180
Shale and sand; 80 percent grayish-red shale; 20 percent very fine to fine, subrounded to angular sand	20	200
Shale and sand; 90 percent grayish-red shale; 10 percent very fine, rounded to angular quartz sand grains	20	220
Shale, grayish-red	70	290
Shale, grayish-red; less than 5 percent frosted grains of very fine; subrounded, quartz sand	10	300
Shale and sandstone; 60 percent grayish-red shale; 40 percent light-gray, frosted quartz, very fine-grained sandstone with rounded to angular, frosted quartz grains	20	320

TABLE 6 (continued)

Stratigraphic unit and material	Thickness (feet)	Depth (feet)
12.10.26.322a Homestake-New Mexico Partners (continued)		
TRIASSIC SYSTEM (continued)		
Chinle formation (continued)		
Shale and sandstone; 80 percent grayish-red shale; 20 percent light-gray, very fine-grained sandstone with round to angular quartz grains	10	330
Shale, grayish-red	20	350
Shale and sandstone; 60 percent grayish-red shale; 40 percent light-gray, very fine-grained sandstone with rounded to angular, frosted quartz grains	20	370
Shale and sandstone; 80 percent grayish-red shale; 20 percent light-gray, very fine-grained quartz sandstone	40	410
Shale and sandstone; 80 percent grayish-red shale; 20 percent light-gray, very fine-grained sandstone in lenses 2 mm wide banded with shale	20	430
Shale, grayish-red	10	440
Shale and limestone; 80 percent grayish-red shale; 20 percent light-brownish-gray; medium-grained crystalline limestone	40	480
Shale, grayish-red	10	490
Shale and limestone; 90 percent grayish-red shale; 10 percent light-brownish-gray limestone	10	500
Shale, pale-red to grayish-red	20	520
Shale and limestone; 90 percent pale-red to grayish-red shale; 10 percent very light-gray, medium-grained crystalline limestone	10	530
Shale, limestone, and sandstone; 70 percent pale-red to grayish-red shale; 20 percent very light-gray, medium-grained crystalline limestone; 10 percent white, fine-grained sandstone	20	550
Shale and limestone; 90 percent grayish-red shale; 10 percent light-gray, medium-grained, crystalline limestone	10	560
Shale, grayish-red	10	570
Shale and sandstone; 90 percent grayish-red shale; 10 percent pale-greenish-yellow, very fine-grained sandstone	10	580
Shale, sandstone, and limestone; 80 percent grayish-red shale; 10 percent pale-greenish-yellow, very fine-grained sandstone; 10 percent light-gray limestone	10	590
Shale, limestone, and sandstone; 60 percent grayish-red shale; 20 percent light-gray limestone; 20 percent light-greenish-yellow, very fine sandstone	10	600

TABLE 6 (continued)

Stratigraphic unit and material	Thickness (feet)	Depth (feet)
12.10.26.322a Homestake-New Mexico Partners (continued)		
TRIASSIC SYSTEM (continued)		
Chinle formation (continued)		
Shale and limestone; 80 percent grayish-red shale; 20 percent light-gray limestone	10	610
Shale, grayish-red	20	630
Shale, grayish-red; micaceous	30	660
Shale and sandstone; 80 percent grayish-red shale; 20 percent light-greenish-yellow, sandstone, very fine grained	10	670
Shale, grayish-red	10	680
Shale and sandstone; 90 percent pale-red shale; 10 percent light-brownish-red very fine-grained sandstone with calcium carbonate cement	10	690
Shale, pale-red	20	710
Shale and sandstone; 90 percent light-gray shale; 10 percent light-gray sandstone with calcium carbonate cement	10	720
Shale, light-gray	30	750
Shale and sandstone; 70 percent pale-red shale; 30 percent light-gray, very fine-grained sandstone	10	760
Shale, pale-red; sandstone and limestone less than 5 percent	30	790
Shale and silty limestone, 60 percent pale-brown shale; 40 percent light-gray to medium-gray grading to moderate-red, silty limestone with mixed texture	10	800
PERMIAN SYSTEM:		
San Andres limestone:		
Sandstone, shale, and limestone; 70 percent very pale-orange to moderate-red, fine-to very coarse-grained and granule sandstone with subrounded to angular grains; 15 percent grayish-red shale; 15 percent light-gray to medium-gray and moderate-red limestone ...	10	810
Sandstone and limestone; 80 percent light-gray to moderate-red, very fine-to medium-grained sandstone with subrounded to angular grains; light-gray to medium-gray, medium-grained crystalline limestone	10	820
Sandstone and limestone; 90 percent moderate-red, very fine-to medium-grained sandstone with subrounded to subangular grains and calcium carbonate cement; 10 percent light-gray to medium-gray, medium-grained crystalline limestone	10	830

TABLE 6 (continued)

Stratigraphic unit and material	Thickness (feet)	Depth (feet)
12.10.26.322a Homestake-New Mexico Partners (continued)		
PERMIAN SYSTEM (continued)		
San Andres limestone (continued)		
Sandstone and limestone; 95 percent yellowish-orange to moderate-red, fine-to medium-grained sandstone with subrounded to angular grains and calcium carbonate cement; 5 percent light-gray to moderate-gray, medium-grained crystalline limestone	10	840
Sandstone, moderate-red, fine-to medium-grained, subrounded to angular with calcium carbonate cement	10	850
Sand, pale-yellowish-brown, very fine to coarse and granular, rounded to angular; 85 percent frosted quartz	20	870
12.10.27.431 W. A. Murray		
QUATERNARY SYSTEM:		
Valley fill:		
Sandstone, grayish-orange, fine- to very coarse-grained, rounded to subrounded, frosted quartz 70 percent, very friable	10	10
Sandstone, grayish-orange, fine- to very coarse-grained, rounded to subrounded; frosted quartz 70 percent; subangular fragment of moderate-red vesicular lava 1 mm across; very friable	10	20
Same as above, except without lava fragments	20	40
Sand, grayish-orange, fine to coarse, rounded to angular; frosted quartz 60 percent	20	60
Sand, grayish-orange, very fine to medium, rounded to subangular; frosted quartz 60 percent	30	90
TRIASSIC SYSTEM:		
Chinle formation:		
Shale and sand; 80 percent grayish-red shale; 20 percent grayish-orange fine to coarse, subrounded to angular grains of frosted quartz sand	10	100
Shale, limestone, and sand; 90 percent grayish-red shale; 5 percent light-gray limestone; 5 percent fine to coarse, subrounded to subangular frosted quartz sand	20	120
Shale, sandstone, limestone, and sand; 80 percent grayish-purple shale; 10 percent light-gray to light-brownish-gray, very fine-grained, subrounded sandstone; 5 percent light-medium-gray limestone; 5 percent fine to medium, subrounded, frosted quartz sand	30	150

TABLE 6 (continued)

Stratigraphic unit and material	Thickness (feet)	Depth (feet)
12.10.27.431 W. A. Murray (continued)		
TRIASSIC SYSTEM (continued)		
Chinle formation (continued)		
Limestone, gravel, and shale; 80 percent light-medium-gray, finely crystalline limestone; 10 percent subrounded gravel; grayish-purple shale	10	160
Limestone, gravel, shale, and sandstone; 70 percent light-medium-gray, finely crystalline limestone, 10 percent subrounded gravel; 10 percent grayish-purple shale, 10 percent grayish-yellow sandstone with calcium carbonate cement; sand grains very fine, subrounded and white	10	170
Shale, limestone, and sandstone; 70 percent moderate-red shale; 20 percent light-medium-gray limestone; 10 percent light-gray, very fine-grained sandstone	20	190
Shale and limestone; 90 percent moderate-red shale; 10 percent medium-gray, finely crystalline limestone	10	200
Shale, moderate-red; contains subrounded fossil fragments	10	210
Shale and limestone; 90 percent moderate-red shale; 10 percent medium-gray limestone	20	230
Shale, limestone, and sandstone; 80 percent grayish-red shale; 15 percent medium-gray, finely crystalline limestone; 5 percent greenish-gray, very fine-grained sandstone	30	260
Shale and limestone; 90 percent grayish-red shale; 10 percent medium-gray limestone	10	270
Shale, grayish-red	30	300
Shale and limestone; 70 percent grayish-red shale; 30 percent light-medium-gray, finely crystalline limestone	10	310
Shale, grayish-red	10	320
Shale, limestone, and gravel; 70 percent grayish-red shale; 25 percent medium-gray, finely crystalline limestone; 5 percent subrounded gravel	10	330
Shale and limestone; 80 percent grayish-red shale; 20 percent medium-gray, finely crystalline limestone	40	370
Shale and limestone; 60 percent grayish-red shale; 40 percent medium-gray, finely crystalline limestone	30	400
Limestone and shale; 50 percent medium-gray, finely crystalline limestone; 50 percent grayish-red shale	30	430

TABLE 6 (continued)

12.10.27.431 W. A. Murray (continued)

Stratigraphic unit and material	Thickness (feet)	Depth (feet)
TRIASSIC SYSTEM (continued)		
Chinle formation (continued)		
Limestone, shale, and sandstone; 45 percent medium-gray, finely crystalline limestone; 45 percent grayish-red shale; 10 percent light-olive-gray, fine-grained sandstone with subrounded grains and calcium carbonate cement	30	460
Shale and limestone; 60 percent grayish-red and medium-dark-gray, calcareous shale; 40 percent medium-gray, finely crystalline limestone	20	480
Shale and sandstone; 70 percent moderate-red and grayish-red-purple shale; 30 percent grayish-orange and moderate-red, very fine-grained sandstone with subrounded to subangular grains	10	490
Shale, moderate-red and grayish-red; micaceous	20	510
Shale and sandstone; 90 percent moderate-red and grayish-red micaceous shale; 10 percent moderate-red sandstone with very fine, subrounded grains and calcareous cement	10	520
PERMIAN SYSTEM:		
San Andres limestone:		
Sandstone, grayish-orange, very fine-to medium-grained; 90 percent rounded to subrounded and frosted quartz grains; minor amounts of limestone; very friable	30	550
Sandstone and limestone; 80 percent grayish-orange sandstone with very fine to medium rounded to subrounded, grains very friable; 20 percent medium-gray, finely crystalline limestone	34	584

TABLE 7

NUMBER OF LARGE-CAPACITY WELLS, ACREAGE IRRIGATED, GROUND WATER USED, AND PRECIPITATION, 1945-57, IN THE GRANTS-BLUEWATER AREA, VALENCIA COUNTY, N. MEX.

Year	Number of wells			Acres irrigated (estimated)		Ground water pumped (acre-feet, estimated)			Surface water used for irrigation (acre-feet, estimated)	Bluewater	
	Irrigation	Industrial	Municipal	Ground water	Surface water	Irrigation	Industrial	Municipal		Precipitation (inches)	Departure (inches)
1945	7	0	2	1,500	1,200?	3,500	0	200	2,400?	8.82	-0.82
1946	16	0	2	4,500	0	9,000	0	200	0	10.76	+1.12
1947	15	0	2	4,500	0	10,300	0	200	0	-	-
1948	19	0	2	4,000	1,500	9,300	0	200	4,630	9.36	- .28
1949	19	0	2	4,000	1,700	6,900	0	225	4,630	11.05	+1.41
1950	22	0	2	6,000	0	11,800	0	250	0	-	-
1951	23	0	2	6,000	0	12,300	0	250	0	-	-
1952	23	2	2	5,000	2,000	10,400	300	270	4,500?	7.71	-1.93
1953	23	3	3	6,000	0	12,000	1,000	320	0	5.41	-4.23
1954	23	3	4	5,000	0	12,600	1,100	380	0	8.43	-1.21
1955	22	4	4	4,500	0	11,500	1,700	400	0	7.34	-2.30
1956	18	5	5	3,600	0	9,250	4,500	460	0	3.30	-6.34
1957	16	4	7	3,300	0	6,750	5,500	550	0	12.00E	+2.36

E - Estimated.

TABLE 8
SUMMARY OF AQUIFER TESTS IN THE GRANTS-BLUEWATER AREA, VALENCIA COUNTY, N. MEX.

Pumped well	Observation well	Method of analysis	Date of test	Pumping rate (gpm)	Coefficient of transmissibility (gpd/ft)	Coefficient of storage
12.10.30.412	12.10.30.412	recovery v. log t/t_1	Feb. 1950	1,740	3,400,000	-
	30.421	drawdown v. log t/r^2	do.	1,740	3,100,000	0.00052
	do.	recovery v. log t/r^2	do.	1,740	3,100,000	.00047
	do.	log drawdown v. log r^2/t	do.	1,740	3,200,000	.00042
	do.	log recovery v. log r^2/t	do.	1,740	3,200,000	.00042
	32.111	drawdown v. log t/r^2	do.	1,740	2,300,000	.0014
	do.	recovery v. log t/r^2	do.	1,740	2,200,000	.00097
	do.	log drawdown v. log r^2/t	do.	1,740	2,500,000	.00081
	do.	log recovery v. log r^2/t	do.	1,740	2,000,000	.0011
12.11.24.411	12.11.24.411	recovery v. log t/t_1	Oct. 1951	600	410,000	-
	do.	do.	do.	775	430,000	-
26.322a	26.322a	do.	Oct. 1956	2,830	460,000	-

TABLE 9
DISCHARGE, DRAWDOWN, AND SPECIFIC CAPACITIES OF WELLS IN THE GRANTS-BLUEWATER AREA, VALENCIA COUNTY, N. MEX.

	Yield		Drawdown below	Specific
Location number	Rate (gpm)*	Date of measurement	static level (feet)≠	capacity (gpm/ft)
11.10. 4.211	680	6-10-48	11.1	61
Do.	730	6-22-51	14.6	50
Do.	950	4-24-52	15.1	63
Do.	515	9- 2-53	5.0	76
8.111	760	9- 4-46	13.6	56
Do.	690	7-10-47	10.8	64
8.122	1,500	8- 5-48	18.2	82
8.221	1,730	7- 8-47	11.0	157
Do.	1,825	4-12-49	4.7	388
Do.	1,410	8-31-54	9.9	142
9.221	1,570	4- 7-47	31.8	49
Do.	1,570	9- 2-53	19.5	80
16.121	2,560	7- 9-47	21.1	121
Do.	2,150	6-11-48	34.7	62
Do.	1,700	8-26-52	25.9	66
16.121a	2,150	8-31-54	26.7	80
27.241	970	6-21-52	25.0	39
12.10.26.322a	2,830	10-15-56	17.9	158
29.434	900	6- 4-47	29	31
29.434a	1,715	11-11-48	8.6	200
Do.	970	9- 2-53	16.3	60
30.412	900	9- 4-46	.8	1,100
Do.	1,745	2- 9-50	2.6	670
30.421	1,110	6- 4-47	15	74
32.111	1,600	4- 7-47	5.7	280
Do.	2,100	5-11-48	11.8	178
Do.	1,520	8-25-52	11.8	129
12.11.15.341	540	5- 6-47	33.4	16
Do.	460	5- 6-47	33.4	14
Do.	400	6- 5-47	33.4	12
Do.	700	8- 5-48	67.5	10
24.411	600	10-18-51	1.4	428
Do.	775	10-22-51	1.8	430
25.213	2,340	7- 8-47	8.8	266
Do.	2,170	8-26-52	16.0	135

* The accuracy of the rates depends on the methods of measuring, which included orifice meter, current meter, and trajectory.

≠ The drawdowns not necessarily based on equivalent periods of pumping.

TABLE 10

CHEMICAL ANALYSES OF WATER FROM WELLS AND SPRINGS IN THE GRANTS-BLUEWATER AREA, VALENCIA COUNTY, N. MEX.

Location number	Owner or name	Date collected	Stratigraphic unit	Temperature (°F)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25° C)	pH
10. 9. 6. 442	Sidney Gottlieb (spring)	5-13-58	Basalt	51	41	206	107	418	595	0	944	275	1.0	1.6	-	2,290	3.11	954	466	49	5.9	3,110	7.7
17.113	Sidney Gottlieb	12- 8-50	Alluvium	57	30	330	380	931	469	0	2,840	754	.7	3.1	-	5,500	7.48	2,390	2,000	46	8.3	6,840	-
23.134	do.	12- 8-50	Chinle fm.	61	8.4	22	9.4	142	321	0	116	12	.8	.3	-	469	.64	94	0	77	6.4	754	-
23.400	Horace Springs	5-13-57	Basalt	61	30	79	40	125	236	4	293	68	.8	2.5	-	778	1.06	362	162	43	2.9	1,170	8.3
26.433	Sidney Gottlieb	12- 8-50	Chinle fm.	67	18	30	14	104	290	0	100	90	.4	4.9	-	423	.58	132	0	63	3.9	668	-
10.10. 3.423	Ojo del Gallo (spring)	12-11-33	San Andres ls.	61	-	124	42	86	338	0	300	55	.0	2.8	-	776	1.06	482	205	28	1.7	-	-
Do.	do.	10-21-44	do.	-	-	117	40	82	336	0	278	48	-	3.8	-	734	1.00	456	181	28	1.7	1,120	-
Do.	do.	7-12-46	do.	61	-	110	41	76	319	0	268	44	.7	5.2	0.18	702	.95	443	182	27	1.6	1,070	-
3.433a	San Rafael Village well	5- 7-57	do.	60	20	107	39	72	320	0	248	42	.4	3.9	-	719	.94	428	166	27	1.5	1,040	7.4
26.331	Monico Mirabal	6-15-55	do.	62	21	109	42	75	314	0	251	60	.8	2.7	-	716	.97	444	187	27	1.5	1,100	7.2
Do.	do.	6- 7-57	do.	63	-	-	-	70	318	0	249	56	-	2.8	.24	-	-	448	165	25	1.4	1,320	7.6
Do.	do.	5-15-58	do.	61	-	-	-	76*	318	0	260	63	-	-	-	-	-	456	196	27	1.6	1,110	7.4
27.333a	Nabor Mirabal	6- 7-57	do.	63	-	-	-	16	250	0	199	22	-	11	.00	-	-	418	213	8	.3	1,000	7.5
10.11.17.231	Malpais Spring	12-12-33	Basalt	40	-	36	8.0	5.8	48	0	6	3.0	.4	3.0	-	135	.18	123	2	9	.2	-	-
11. 9.30.122a	O. H. Hawkinson	8- 2-56	Alluvium	-	-	-	-	-	575	0	-	408	-	-	-	-	-	550	79	-	-	3,760	7.7
11.10. 4.211	John Evans	8- 5-48	San Andres ls.	58	-	-	-	-	296	0	-	28	-	-	-	-	-	-	-	-	-	972	-
Do.	do.	8-10-53	do.	-	-	-	-	-	296	0	-	31	-	-	-	-	-	-	-	-	-	1,040	-
Do.	do.	6-15-55	do.	58	-	-	-	-	296	0	-	33	-	-	-	-	-	480	242	-	-	1,070	7.3
Do.	do.	7-17-56	do.	58	-	-	-	54	286	0	291	31	-	14	-	-	-	436	202	26	1.5	1,050	7.5
Do.	do.	6- 7-57	do.	59	-	-	-	-	284	0	277	31	-	17	.04	-	-	490	258	15	.8	1,300	7.6
4.311	do.	7-24-56	do.	57	-	-	-	38	258	0	252	28	-	19	-	-	-	446	234	16	.8	932	8.2
5.212	do.	7-17-56	do.	56	-	-	-	40	261	0	253	21	-	15	-	-	-	432	218	17	.8	930	7.5
Do.	do.	6- 7-57	do.	55	-	-	-	33	262	0	255	22	-	12	.04	-	-	448	234	14	.7	-	7.5
8.111	Salvador Milan	7-11-46	do.	58	-	60	32	20	225	0	122	8	.7	.7	.04	354	.48	281	96	14	.5	581	-
8.111a	do.	10-21-44	do.	-	-	80	40	39	253	0	200	18	-	10	-	512	.70	364	156	19	.9	805	-
8.221	do.	5-29-54	do.	-	-	-	-	38	268	0	207	20	.3	12	-	-	-	390	170	18	.8	866	-
Do.	do.	7-17-56	do.	56	-	-	-	33	263	0	212	22	-	21	-	-	-	412	196	15	.7	864	7.6
8.343	do.	7-17-56	do.	62	-	-	-	22	230	0	119	8	-	8.4	-	-	-	284	96	14	.6	609	7.8
9.221	Stanley and Card	7-11-46	do.	55	-	101	31	51	287	0	211	20	.7	7.3	.07	563	.77	380	144	23	1.1	856	-
Do.	do.	7-19-56	do.	56	-	-	-	62	284	0	285	29	-	10	-	-	-	444	212	23	1.3	1,030	7.6
Do.	do.	6- 7-57	do.	59	-	-	-	47	290	0	286	29	-	10	.16	-	-	482	244	17	.9	-	7.5
16.121**	Frank Wilson	1945(?)	do.	-	-	113	30	55	281	0	230	34	-	9	-	752	1.02	404	-	23	1.2	-	-
Do.	do.	7-12-46	do.	55	-	110	30	45	271	0	218	16	.7	27	.07	580	.79	398	176	20	1.0	872	-
Do.	do.	9- 51	do.	55	-	-	-	-	272	0	-	17	-	-	-	-	-	-	-	-	-	801	-
16.121a	Lee Hanosh	8-11-53	do.	-	-	-	-	-	269	0	-	18	-	-	-	-	-	-	-	-	-	799	-
Do.	do.	7-17-56	do.	56	-	-	-	35	266	0	191	18	-	13	-	-	-	376	158	17	.8	812	7.6
21.221	Salvador Milan	6- 7-57	Alluvium	-	25	39	51	39	256	0	147	15	.4	8.2	.03	451	.61	307	97	22	1.0	898	7.6
21.242	do.	7-24-56	do.	62	-	-	-	29*	254	0	168	21	-	-	-	-	-	350	142	15	.7	761	7.6
22.311	W. A. Thigpen	7-24-56	do.	62	-	-	-	38*	214	0	238	57	-	-	-	-	-	422	246	16	.8	942	7.6
26.321	Grants City Well 3	5- 7-57	do.	60	-	-	-	77	347	0	285	53	-	3.1	.07	-	-	490	206	26	1.5	1,170	7.4
26.321a	Grants City Well 2	10-21-44	do.	-	-	97	32	52	269	0	199	27	.3	5.7	-	555	.75	374	136	23	1.2	863	-
Do.	do.	6-15-55	do.	59	28	118	38	67	328	0	255	41	.6	3.8	-	712	.97	450	182	25	1.4	1,070	7.4
26.321b	Grants City Well 1	12-16-33	do.	-	-	134	46	115	370	0	350	75	.4	0	-	903	1.23	524	220	32	2.2	-	-
26.321c	Grants City Well 4	6-27-58	San Andres ls.	-	-	-	-	236*	541	0	557	155	-	-	-	-	-	730	286	42	3.9	2,110	6.9
Do.	do.	12-15-58	do.	73	15	175	57	192	472	0	498	129	.2	1.0	-	1,350	1.77	671	284	38	3.2	1,880	7.0
12. 9. 8.431	C. P. Roundy	7-25-56	Chinle fm.	58	-	-	-	163*	246	18	57	53	-	-	-	-	-	12	0	97	20	852	8.9
12.10. 1.222	do.	7-24-56	do.	57	-	-	-	5,740*	34	0	1,350	8,590	-	-	-	-	-	2,470	2,440	83	50	27,600	6.8
7.143	Duane Berryhill	6-27-56	San Andres ls.	-	-	-	-	198	502	0	553	126	-	.3	-	-	-	735	324	37	3.2	2,020	7.1
23.233	T. A. Morris & Son	7-12-46	do.	-	-	254	88	379	702	0	829	270	.4	.6	.28	2,170	2.95	996	420	45	5.2	3,040	-
Do.	do.	6- 4-47	do.	-	-	-	-	-	669	0	794	238	-	-	-	-	-	-	-	-	-	2,880	-
Do.	do.	8- 4-48	do.	68	-	-	-	-	688	0	-	250	-	-	-	-	-	-	-	-	-	2,960	-
Do.	do.	8-18-49	do.	68	-	-	-	-	686	0	-	254	-	-	-	-	-	-	-	-	-	2,960	-

See footnotes at end of table.

TABLE 10 (continued)

Location number	Owner or name	Date collected	Stratigraphic unit	Temperature (°F)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25° C)	pH
12.10.23.233	T. A. Morris & Son	10-16-50	San Andres ls.	68	-	-	-	-	668	0	-	239	-	-	-	-	-	-	-	-	-	2,900	-
Do.	do.	6-25-52	do.	69	-	-	-	-	682	0	-	245	-	-	-	-	-	-	-	-	-	2,930	-
Do.	do.	8-25-52	do.	69	-	-	-	-	675	0	-	250	-	-	-	-	-	-	-	-	-	2,910	-
Do.	do.	10- 6-54	do.	-	-	-	-	426*	360	0	604	53	-	0	-	-	-	72	0	93	22	1,930	-
Do.	do.	8-10-55	do.	-	-	-	-	346*	656	0	772	242	-	-	-	-	-	930	392	45	4.9	2,860	6.8
23.233a	G. P. Roundy	7-12-46	Chinle fm.	-	-	40	11	458	392	0	733	37	0.4	4.4	0.55	1,480	2.01	145	0	87	17	2,130	-
26.242	Homestake-Sapin Partners	5-22-58	San Andres ls.	68	16	214	74	302	617	0	671	205	.5	1.2	-	1,790	2.43	838	333	44	4.5	2,500	-
26.322a	Homestake-New Mexico Partners	10-15-56	do.	-	15	65	128	153	466	0	467	106	.7	3.2	-	1,170	1.59	688	306	33	2.5	1,810	7.0
27.244	T. A. Morris & Son	7-25-56	Alluvium	57	-	-	-	250	284	0	608	86	-	10	-	-	-	660	428	45	4.2	2,060	7.7
27.333	Stanley and Card	10- 6-54	San Andres ls.	-	-	-	-	106	377	0	394	65	-	11	-	-	-	590	281	28	1.9	1,430	-
Do.	do.	7-17-56	do.	60	-	-	-	102	377	0	407	65	-	9.5	-	-	-	610	301	27	1.8	1,450	7.3
Do.	do.	5- 7-57	do.	60	-	-	-	107	377	0	407	65	-	9.1	.33	-	-	598	289	28	1.9	1,440	7.3
27.431	W. A. Murray	7-25-56	do.	59	-	-	-	118	392	0	392	72	-	6.9	-	-	-	580	259	31	2.1	1,450	7.3
29.434	Stanley and Card	7-12-46	Alluvium	55	-	94	26	40	232	0	194	16	.5	14	.04	499	.68	342	152	20	.9	765	-
29.434a	do.	6-28-56	San Andres ls.	55	-	-	-	97	257	0	517	58	-	31	-	-	-	645	434	25	1.7	1,480	7.4
Do.	do.	5-14-58	do.	56	-	-	-	93*	263	0	504	58	-	-	-	-	-	620	404	25	1.6	1,460	7.6
30.112	The Anaconda Co.	7-18-56	do.	-	-	-	-	32	291	0	134	16	-	32	-	-	-	356	118	17	.7	779	7.7
Do.	do.	5- 8-57	do.	60	-	-	-	31	286	0	135	24	-	58	-	-	-	388	154	15	.7	835	7.4
30.242	Jack Freas	8-12-53	Alluvium	-	-	-	-	-	366	0	-	22	-	-	-	-	-	-	-	-	-	981	-
Do.	do.	6-28-56	do.	-	-	-	-	18	325	0	178	24	-	26	-	-	-	468	202	8	.4	906	7.5
Do.	do.	5- 7-57	do.	62	-	-	-	20	327	0	172	24	-	20	-	-	-	454	186	9	.4	885	7.7
30.412**	Fred W. Freas	1945(?)	San Andres ls.	-	-	158	75	6	386	0	300	46	-	26	-	997	1.35	702	-	-	-	-	-
30.412	do.	5-10-46	do.	55	-	130	41	29	251	0	259	38	.3	32	-	653	.89	493	288	11	.6	1,000	-
Do.	do.	8- 5-48	do.	55	-	-	-	-	346	0	-	38	-	-	-	-	-	-	-	-	-	1,100	-
Do.	do.	8-18-49	do.	55	-	-	-	-	349	0	-	37	-	-	-	-	-	-	-	-	-	1,130	-
Do.	do.	9- 51	do.	56	-	-	-	-	344	0	-	36	-	-	-	-	-	-	-	-	-	1,160	-
Do.	do.	6-25-52	do.	-	-	-	-	-	350	0	-	38	-	-	-	-	-	-	-	-	-	1,140	-
Do.	do.	8-10-55	do.	56	-	-	-	36*	342	0	270	38	-	-	-	-	-	536	256	13	.7	1,150	7.3
Do.	do.	6- 5-56	do.	-	-	-	-	86*	354	0	394	65	-	-	-	-	-	605	315	24	1.5	1,450	7.6
Do.	do.	7-18-56	do.	56	-	-	-	55	330	0	304	39	-	30	-	-	-	546	280	18	1.0	1,170	7.5
30.421	Milton Harding	8-11-53	do.	-	-	-	-	-	352	0	-	37	-	-	-	-	-	-	-	-	-	1,160	-
Do.	do.	7-18-56	do.	56	-	-	-	40	323	0	317	38	-	27	-	-	-	570	306	15	.8	1,170	7.5
Do.	do.	5- 7-57	do.	59	-	-	-	46	315	0	282	35	-	26	.07	-	-	524	266	16	.9	1,100	7.4
30.433	Fred W. Freas	10-21-44	do.	-	-	98	39	51	299	0	190	33	-	32	-	590	.80	405	160	21	1.1	919	-
32.111	The Anaconda Co.	7-12-46	do.	-	-	126	42	50	308	0	268	32	.5	21	.07	691	.94	487	234	18	1.0	1,050	-
Do.	do.	6-15-55	do.	55	-	-	-	-	295	0	-	30	-	22	-	-	-	520	278	-	-	1,100	7.3
Do.	do.	7-18-56	do.	56	-	-	-	41	281	0	295	23	-	14	-	-	-	492	262	15	.8	1,040	7.5
33.444	Stanley and Card	6-28-56	Chinle fm.	55	-	-	-	265	404	0	327	12	-	2.4	-	-	-	115	0	83	11	1,310	8.2
Do.	do.	5- 7-57	do.	58	-	-	-	254	420	0	307	13	-	.2	-	-	-	130	0	81	9.7	1,270	7.8
34.214	W. A. Murray	7-17-56	do.	56	-	-	-	719	189	0	1,590	74	-	14	-	-	-	364	209	81	16	3,530	7.9
34.412	J. E. Church	8-28-56	Chinle and San Andres fms.	55	-	-	-	378	305	0	563	88	-	.6	-	-	-	138	0	86	14	1,900	7.8
12.11. 3.112a	Floyd M. Gibbs	1-28-58	Chinle fm.	-	-	-	-	168*	251	27	109	33	-	-	-	-	-	46	0	89	11	782	9.1
9.114a†	Bruce Church	2- 3-48	San Andres ls.	-	13	160	105	150	450	0	632	91	.2	1.5	-	1,370	1.86	830	462	28	2.3	1,940	-
9.424	George W. Rowley	7-12-46	San Andres and Yeso fms.	-	-	700	131	1,220	1,620	0	2,300	860	2.1	1.3	.73	6,010	8.17	2,280	958	54	11	7,680	-
9.424‡	do.	1- 47	do.	-	-	-	-	-	305§	0	-	925	-	-	-	-	-	-	-	-	-	6,790	-
9.424||	do.	2- 47	do.	-	-	254	121	1,250	270§	0	2,270	900	-	.4	-	4,930	6.70	1,130	910	71	16	6,610	-
9.424	do.	6-13-55	do.	-	-	-	-	-	1,600	0	-	865	-	-	-	-	-	2,250	939	54	11	7,490	6.6
10.334	J. W. Price	6-16-55	San Andres ls.	-	-	-	-	-	528	0	693	165	-	-	-	-	-	880	448	37	3.4	2,360	7.0
Do.	do.	6- 7-57	do.	60	-	-	-	235	558	0	752	184	-	2.0	.48	-	-	990	532	34	3.3	3,110	7.0
10.431	Burton C. Johns	5-10-46	do.	59	-	178	47	155	429	0	462	98	.3	3.6	-	1,160	1.58	638	286	35	2.7	1,700	-
Do.	do.	6- 5-47	do.	-	-	-	-	-	468	0	525	112	-	-	-	-	-	-	-	-	-	1,880	-

See footnotes at end of table.

TABLE 10 (continued)

Location number	Owner or name	Date collected	Stratigraphic unit	Temperature (°F)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Parts per million	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$: Calcium, Magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25° C)	pH
12.11.10.431	Burton C. Johns	8-11-53	San Andres ls.	-	-	-	-	-	536	0	-	158	-	-	-	-	-	-	-	-	-	2,310	-
Do.	do.	6-16-55	do.	59	-	-	-	-	530	0	-	164	-	-	-	-	-	830	396	-	-	2,300	7.0
11.334	Duane Berryhill	6-27-56	Alluvium and basalt	-	-	-	-	33	247	0	258	32	-	16	-	-	-	458	256	13	0.7	960	7.3
Do.	do.	5- 9-57	do.	60	-	-	-	29	243	0	252	32	-	14	-	-	-	454	255	12	.6	925	7.7
13.233#	The Anaconda Co.	7-18-56	-	-	32	679	276	1,170	177	0	3,940	86	0.5	1,250	-	7,520	10.2	2,830	2,680	47	9.6	7,580	7.6
13.431#	do.	7-25-56		-	-	-	-	-	-	-	-	-	-	353	-	-	-	-	-	-	-	5,720	-
14.213	Duane Berryhill	7-23-56	Alluvium and basalt	57	-	-	-	22	232	0	119	8	-	.9	-	-	-	278	88	15	.6	604	7.4
Do.	do.	6- 7-57	do.	66	24	102	34	33	264	0	211	17	.4	6.6	0	558	.76	394	178	15	.7	1,020	7.5
14.311	Fred W. Freas	10-21-44	do.	-	-	114	28	24	264	0	184	10	-	36	-	526	.72	400	183	11	.5	786	-
Do.	do.	7-12-46	do.	-	-	118	31	19	261	0	199	12	.7	30	.04	538	.73	422	208	9	.4	810	-
Do.	do.	8-11-53	do.	-	-	-	-	-	283	0	-	52	-	-	-	-	-	-	-	-	-	1,120	-
14.331	G. P. Roundy	7-18-56	do.	57	-	-	-	11	256	0	188	28	-	16	-	-	-	435	225	5	.2	844	7.6
Do.	do.	5- 8-57	do.	60	-	-	-	17	261	0	198	31	-	16	-	-	-	440	226	8	.3	858	7.9
15.211	do.	6-27-56	San Andres ls.	58	-	-	-	225	515	0	675	162	-	7.0	-	-	-	870	448	36	3.3	2,320	6.9
Do.	do.	5- 6-57	do.	59	-	-	-	220	514	0	668	161	-	6.6	1.2	-	-	870	449	36	3.2	2,290	7.0
Do.	do.	5-14-58	do.	59	-	-	-	254*	542	0	741	175	-	-	-	-	-	910	466	38	3.7	2,430	7.0
15.341	E. C. Freas	5- 6-47	do.	55	-	153	45	96	354	0	379	59	.4	8.1	-	915	1.24	566	276	27	1.8	1,340	-
Do.	do.	8- 5-48	do.	55	-	-	-	-	396	0	-	79	-	-	-	-	-	-	-	-	-	1,540	-
16.230	E. B. Bowlin	1- 47	Yeso(?) fm.	-	-	228	100	1,840	920	0	3,370	505	-	.5	-	6,500	8.84	980	226	80	26	7,940	-
20.422	J. F. Nielson	12- 46	do.	-	-	68	35	14	295	13	46	20	-	5.3	-	346	.47	314	50	9	.3	596	-
Do.	do.	8-12-53	do.	-	-	-	-	-	329	0	-	20	-	-	-	-	-	-	-	-	-	615	-
Do.	do.	7-19-56	do.	57	-	-	-	12	323	0	35	19	-	.1	-	-	-	303	38	8	.3	601	7.5
22.234	Church of Latter Day Saints	6- 5-47	San Andres ls.	-	-	266	68	18	161	0	800	12	-	.4	-	1,240	1.69	943	811	4	.3	1,520	-
Do.	do.	8-11-53	do.	-	-	-	-	-	267	0	-	26	-	-	-	-	-	-	-	-	-	1,370	-
22.322	George W. Rowley	10-21-44	-	-	-	168	53	99	359	0	379	56	-	305	-	1,040	1.41	638	344	25	1.7	1,470	-
22.420	A. Tietgen	12-14-33	San Andres(?) ls.	-	-	172	46	76	352	0	356	50	0	68	-	941	1.28	618	330	21	1.3	-	-
23.231	G. P. Roundy	6- 4-47	San Andres ls.	-	-	121	30	9.4	305	0	158	12	-	18	-	499	.68	426	176	5	.2	794	-
Do.	do.	9- 51	do.	56	-	-	-	-	294	0	-	16	-	-	-	-	-	-	-	-	-	-	-
Do.	do.	10-28-52	do.	-	23	137	32	1.2	288	0	164	22	.2	47	-	568	.77	474	238	1	0	899	-
Do.	do.	8-12-53	do.	-	-	-	-	-	300	0	-	20	-	-	-	-	-	-	-	-	-	925	-
Do.	do.	6-27-56	do.	-	-	-	-	12	283	0	207	32	-	76	-	-	-	528	296	5	.2	1,010	7.2
Do.	do.	7-18-56	do.	-	-	-	-	-	-	0	-	31	-	75	-	-	-	-	-	-	-	997	-
Do.	do.	5- 8-57	do.	60	-	-	-	10	293	0	212	36	-	73	-	-	-	548	308	4	.2	1,030	7.4
24.233	The Anaconda Co.	12- 6-55	do.	58	-	-	-	84*	346	0	330	57	-	-	-	-	-	524	240	26	1.6	1,270	7.2
Do.	do.	7-18-56	do.	59	15	142	42	105	351	0	351	60	.5	19	-	908	1.23	527	240	30	2.0	1,330	7.4
Do.	do.	5- 7-57	do.	-	-	-	-	134	338	0	482	65	-	56	-	-	-	624	347	32	2.3	1,590	7.3
24.334	Peter Chalamidas	6-28-56	do.	-	-	-	-	90	392	0	386	79	-	13	-	-	-	650	329	23	1.5	1,470	7.2
Do.	do.	6- 7-57	do.	-	-	-	-	87	414	0	382	75	-	15	-	-	-	665	326	22	1.5	-	7.4
24.411	The Anaconda Co.	4-23-52	do.	56	15	165	49	103	402	0	380	70	.5	15	-	996	1.35	613	284	27	1.8	1,460	7.2
Do.	do.	12- 6-55	do.	56	-	-	-	-	363	0	355	63	-	-	-	-	-	556	258	26	1.7	1,350	7.5
Do.	do.	6- 4-56	do.	-	-	-	-	-	326	0	282	38	-	-	-	-	-	540	273	10	.5	1,140	7.4
Do.	do.	7-18-56	do.	58	16	139	45	95	348	0	342	59	.3	18	-	885	1.20	532	247	28	1.8	1,320	7.4
Do.	do.	5- 7-57	do.	60	20	160	56	141	295	0	523	68	.3	65	-	1,180	1.60	630	388	33	2.4	1,630	7.5
Do.	do.	5-14-58	do.	58	-	-	-	-	387	0	552	79	-	-	-	-	-	725	408	-	-	1,790	7.3
25.122	do.	6-27-56	do.	-	-	-	-	42	326	0	278	47	-	35	-	-	-	560	293	14	.8	1,150	7.4
25.213	do.	7-11-46	do.	-	-	147	49	95	366	0	356	57	.6	29	.15	914	1.24	568	268	27	1.7	1,320	-
Do.	do.	9- 51	do.	56	-	-	-	-	361	0	-	57	-	-	-	-	-	-	-	-	-	1,340	-
Do.	do.	7-18-56	do.	57	17	145	52	88	338	0	365	55	.3	40	-	928	1.26	576	299	25	1.6	1,340	7.4
Do.	do.	5- 7-57	do.	60	21	145	49	84	341	0	353	54	.8	27	.33	902	1.23	564	284	25	1.5	1,320	7.2
25.214	do.	8-12-53	do.	-	-	-	-	-	358	0	-	55	-	-	-	-	-	-	-	-	-	1,320	-
25.313	Harmon and Reid	6- 4-47	do.	-	-	119	46	66	323	0	266	52	-	18	-	726	.99	486	222	23	1.3	1,120	-
Do.	do.	7-19-56	do.	57	17	77	34	27	266	0	138	16	.4	7.6	-	448	.61	332	114	15	.6	722	7.7

* Sodium and potassium concentration computed without regard to fluoride and nitrate concentrations.
** Analyzed by University of Arizona.
≠ Sample collected during well drilling process at depth of 178 feet; well completed at 523 feet.
ƒ Sample collected just after pump was started.
§ Sample contained precipitated $CaCO_3$ at time of analysis.
‖ Sample collected after 10 hours of continuous pumping.
Effluent from mill pond, The Anaconda Co.

TABLE 11

COMPARISON OF CHEMICAL ANALYSES OF WATER FROM WELL 12.10.23.233 AND A WELL IN THE SE¼ SEC. 22, T. 14 N., R. 10 W., N. MEX.

	12.10.23.233 Aug. 10, 1955*		SE¼ sec. 22, T. 14 N., R. 10 W. Nov. 21, 1956*	
	ppm	epm	ppm	epm
Calcium	-	(18.60	262	13.07
Magnesium	-	(	94	7.73
Sodium and Potassium	346	15.05	373	16.20
Carbonate	0	.00	0	.00
Bicarbonate	656	10.75	531	8.70
Sulfate	772	16.07	1,030	21.44
Chloride	242	6.82	242	6.82
Hardness as $CaCO_3$	930	-	1,040	-
Noncarbonate	392	-	605	-
Specific conductance (micromhos at 25° C)	2,860	-	3,100	-
pH	6.8	-	6.7	-

*Date of collection.

TABLE 12

COMPARISON OF MUNICIPAL-WATER SUPPLIES IN THE GRANTS-BLUEWATER AREA, VALENCIA COUNTY, N. MEX., WITH RECOMMENDED STANDARDS OF THE U.S. PUBLIC HEALTH SERVICE

Constituent	Public Health Standard a	San Rafael b	Milan c	Grants d	Bluewater e
Iron and manganese	0.3	-	-	-	-
Magnesium	125	39	51	57	68
Sulfate	250	248	147	498	800
Chloride	250	42	15	129	12
Fluoride	1.5	.4	.4	.2	-
Dissolved solids	500f	719	451	1,350	1,240

a. Standards set forth by the U. S. Public Health Service, 1946, Drinking-water standards: Public Health Reports, v. 61, no. 11, p. 371-384.

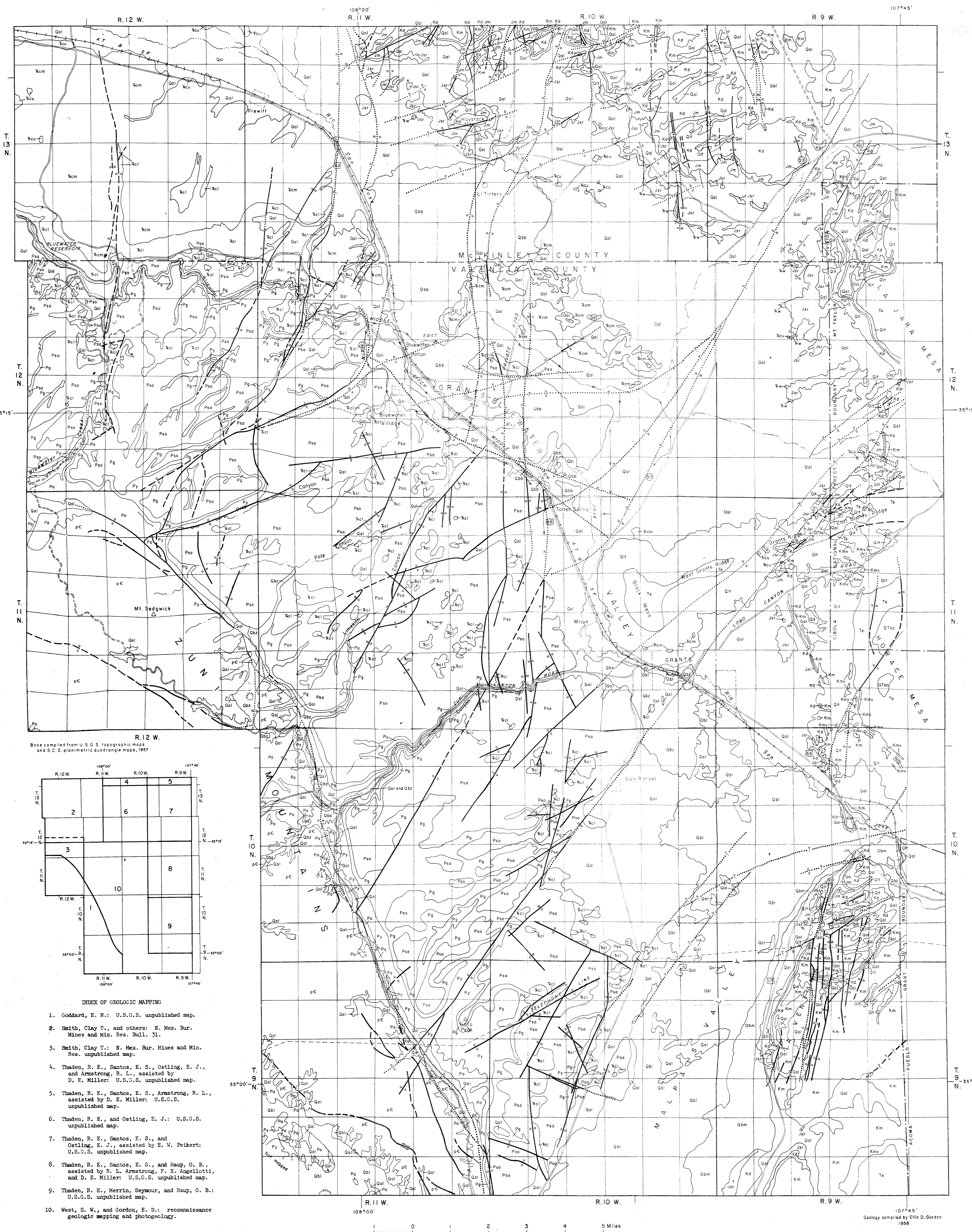
b. Well 10.10.3.433a; 5-7-57; San Rafael village well.

c. Well 11.10.21.221; 6-7-57; Salvador Milan.

d. Well 11.10.26.321c; 12-15-58; Grants City well 4.

e. Well 12.11.22.234; 6-5-47; Church of Latter Day Saints.

f. 1,000 ppm permitted, if water of better quality is not available.



INDEX OF GEOLOGIC MAPPING

1. Goddard, E. N.: U.S.G.S. unpublished map.
2. Smith, Clay T., and others: N. Mex. Bur. Mines and Min. Res. Bull. 31.
3. Smith, Clay T.: N. Mex. Bur. Mines and Min. Res. unpublished map.
4. Thaden, R. E., Santos, E. S., Ostling, E. J., and Armstrong, R. L., assisted by D. E. Miller: U.S.G.S. unpublished map.
5. Thaden, R. E., Santos, E. S., Armstrong, R. L., assisted by D. E. Miller: U.S.G.S. unpublished map.
6. Thaden, R. E., and Ostling, E. J.: U.S.G.S. unpublished map.
7. Thaden, R. E., Santos, E. S., and Ostling, E. J., assisted by E. W. Peikert: U.S.G.S. unpublished map.
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RLB

EXPLANATION

QUATERNARY

Pleistocene and Recent

Qal

Alluvium

Unconsolidated silt, clay, sand, and gravel. Locally may overlie, intertongue with, or underlie Quaternary basalt. Yields adequate quantities of water to shallow wells for stock and domestic supplies at many places, and for irrigation locally

Qbb | Qbl | Qbm | Qbz

Basalt

Dark-gray to black dense to vesicular basalt, ash, and cinders emplaced as low cones and valley flows.
Qbb, Bluewater basalt flow
Qbl, Laguna basalt flow
Qbm, McCartys basalt flow
Qbz, Zuni Canyon basalt flow
Yields adequate quantities of water to shallow wells for stock and domestic supplies at many places

Qlt

Landslide and talus material

Qsl

Spring-deposited limestone

Pliocene and Pleistocene(?)

QTbc

Basaltic cinder cones, plugs, and dikes

TERTIARY

Pliocene

Te

Extrusive rocks

Flow rocks capping Horace Mesa and Grants Ridge; include some rhyolite and tuff breccia; include some small areas of intrusive rocks in East Grants Ridge

CRETACEOUS

Upper Cretaceous

Kmv

Mesaverde group

Gray to yellowish-buff silty shale and thin- to thick-bedded fine-grained sandstone and local coal beds. Water-bearing properties in Grants-Bluewater area not determined; yields adequate quantities of water for stock and domestic supplies in adjacent areas

Km

Mancos shale

Platy, calcareous dark-gray marine shale; some thick-bedded sandstone in lower part. Water-bearing properties in Grants-Bluewater area not determined

Lower(?) and Upper Cretaceous

Kd

Dakota sandstone

Massive medium- to coarse-grained yellowish-buff sandstone, containing interbedded siltstone locally. Water-bearing properties in Grants-Bluewater area not determined; yields adequate quantities of water for stock and domestic supplies in adjacent areas

JURASSIC

Middle and Upper Jurassic

Jm

Morrison formation

Varicolored claystone and siltstone interbedded with fine- to medium-grained sandstone. Includes Recapture shale, Westwater Canyon sandstone, and Brushy Basin shale members. Water-bearing properties in Grants-Bluewater area not determined; yields adequate quantities of water for stock and domestic supplies in adjacent areas

Jsr

San Rafael group

Fine- to medium-grained varicolored sandstone, in part silty, and claystone; contains some limestone in lower part and massive crossbedded reddish-brown to orange sandstone in basal part. Includes or is equivalent to Zuni sandstone, Entrada sandstone, Todilto limestone, Summerville formation, and Bluff sandstone. Yields adequate quantities of water for stock and domestic supplies in northern and eastern parts of area

TRIASSIC

Upper Triassic

Ꝗw

Wingate sandstone

Massive crossbedded reddish-brown to orange sandstone. Yields adequate water for stock and domestic supplies

Ꝗcu
Ꝗcm
Ꝗcl

Chinle formation

Variegated siltstone and mudstone containing interbedded silty and conglomeratic sandstone. Contains some thin beds of limestone in the upper part, a thick sandstone unit near the middle, and considerable sandstone in the lower part; coarse-grained to conglomeratic sandstone occurs locally in basal part. ~~Divided~~
Ꝗcu, upper part
Ꝗcm, middle part
Ꝗcl, lower part
The sandstone units yield adequate quantities of water for stock and domestic supplies

PERMIAN

Psa

San Andres limestone

Thick-bedded to massive light-gray limestone, sandy limestone, and limy sandstone. The limestone is locally cavernous. Yields adequate quantities of water for irrigation, industrial, and municipal supplies

Pg

Glorieta sandstone

Thick-bedded to massive well-sorted medium-grained white to yellowish-gray sandstone with limonitic flecks. Some siltstone interbedded in lower part. Yields water to irrigation, industrial, and municipal wells. Contributes water by vertical leakage to the San Andres limestone in areas of heavy pumpage from the San Andres

Py

Yeso formation

Orange to red siltstone and fine-grained silty sandstone, containing a few thin beds of limestone in the lower middle part and thick-bedded to massive crossbedded fine-grained silty sandstone in basal part. Partly gypsiferous. Yields adequate quantities of water for stock and domestic supplies

Pa

Abo formation

Dark-brick-red to reddish-brown arkosic sandstone and siltstone; partly conglomeratic in basal part. Water-bearing properties in Grants-Bluewater area not determined. Includes strata of possible Pennsylvanian age

PRECAMBRIAN

p€

Precambrian rocks undivided

Granite, gneiss, metarhyolite, schist, and greenstone

Contact between geologic formations

D
U

Fault; dashed where approximately located or doubtful; dotted where covered (D, downthrown block; U, upthrown block)

Volcanic cone

PLATE 1

GEOLOGIC MAP OF THE GRANTS-BLUEWATER AREA, VALENCIA AND MC KINLEY COUNTIES, N. MEX.